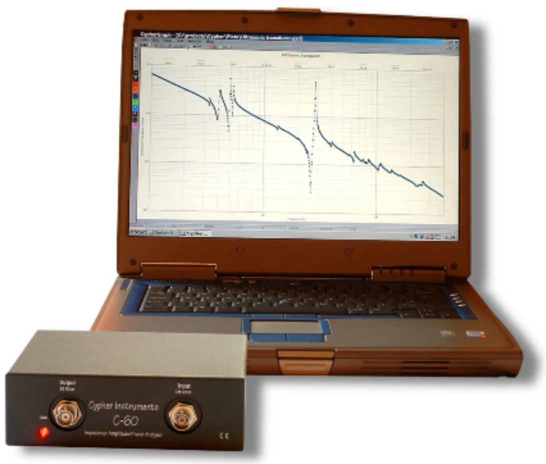
Cypher Instruments



C60 System - User Manual

- Measure frequency responses from 10Hz to 4MHz
- Frequency axis displayed logarithmically or linearly
- Measure amplitude responses
- Gain or loss displayed in dBs
- Measure phase responses
- Phase display ranges of 0^{o} to 180^{o} or $\pm 180^{o}$
- Measure complex impedance responses
- Display impedance in Ohms or admittance in Siemens
- Calculate time delays
- Produce professional graphs with 10 plots per graph
- Interactive powerful graphing program
- Save graphs as data files and jpg, bmp and meta files
- Copy and paste plots from one graph to another
- Easy to use PC interface
- Reliable performance
- Small, light weight, portable, USB powered device
- Affordable

www.cypherinstruments.co.uk

Contents

Preface *written by Tim Orr*

I have been designing electronic filters for about 35 years. These have been active and passive devices. Since the arrival of personal computers and design software, it has been possible to design and simulate a wide variety of filters. Of course, in the real world, you cannot purchase the precise component values that this software generates. Also, real components are far from perfect. Capacitors and inductors have parasitic elements and natural resonances; op amps have bandwidth, slew rate and phase shift problems and printed circuit board tracks seem to do their very best to defeat your designs. Even if you can over come all these hurdles, a design still has to be built and tested. This is also a problem because there isn't much equipment out there that will test filters and networks at a price that the average engineer can justify spending.

Recently, the frequency response analyser that I purchased 15 years ago, became unusable because its consumables have been discontinued. I needed to obtain a new piece of test equipment just to satisfy my own needs! I had designed many frequency response analysers over the last 30 years, and so we set out to produce another unit based on what was the best current technology. The plan was to make a USB peripheral device that would employ all the power of the PC to produce, store and print graphs. After 2 years of design work (mission creep) the C60 was produced. One result of deviation from the original design brief was that the unit not only measures Amplitude and Phase frequency responses, but it also measures Impedance responses. This reveals the often bizarre behaviour of electronic and electro-acoustic devices. I wish that I had owned one of these machines 10 years ago when we were designing ceramic PZT transducers. Many mysteries would have been easily observed, rather than just guessed. Any way, that's life**.**

Adam Fullerton
Software & Firmware

Rene Fullerton
Logistics

Tim Orr
Electronics

Legal Disclaimer, Warnings and Restrictions

The C60 has a low impedance output and a very sensitive input. Passive electronic circuits inside the unit provide a level of protection to these ports, even when the unit is powered down. Do not exceed the voltage and current restrictions applied to the input and output connectors, as specified in this manual. These are not operating conditions, they are dangerous limits. Applying excessive voltages and currents will cause dangerous power dissipation inside the C60 which can result in unexpected operational behaviour and/or permanent damage.

WARNING:- Do not connect high voltages to any connector or other part of the C60. These voltages will damage the C60 and other equipment to which it is electrically connected, such as the computer. Also, these high voltages are dangerous and represent a risk to health.

Customers are responsible for their testing scenarios and interpretations of test results. Persons using the product must have a scientific or engineering training, be familiar with the use of personal computers and must observe good laboratory test methods and standards. Cypher Instruments assumes no liability for customers test results and interpretations. The customer assumes all responsibility and liability for the proper use of the equipment and software.

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Cypher Instruments does not warrant the completeness or the accuracy of the text, information, graphics graphs, equations, diagrams or other material contained within the product manual.

The product is designed to operate in a laboratory at normal room temperatures. Operation at extreme temperatures may result in unexpected behaviour. The unit has no harsh environmental ratings and will be damaged by the ingress of moisture and/or corrosive chemicals. It has an IP30 rating:- prevention of small objects bigger than 2.5mm from entering and no protection against the ingress of liquids.

Product Description

The C60 investigates the opaque world of analogue networks. The unit operates in two test modes. It can measure the frequency response of a two port system producing a **gain/loss & phase** graph. It can also measure the reactive response of a two terminal network producing an **impedance/admittance & phase** graph. Electronic, electrical, electro acoustic and other networks can be tested with swept sine waves and the results displayed on a PC. The C60 is USB powered; it needs no batteries or external power supplies. The unit has a USB-B connector at the rear, an input and output BNC connector and a USB Link activity LED. All the functionality of the device is controlled by the PC.

DDS Sine wave generator/output
Frequency range of sine wave generator = 10Hz to 4MHz DDS sine wave generator Sine wave quality = 62dB SNAD (nominal) Output voltage = 2Vpp maximum Output attenuator, 0dB to -20.0dB in 2.5dB steps DC offset at output = 0.9mV typical Output impedance = 50 Ohms plus parasitic reactance of 23nH and 33pF (Impedance mode) Frequency accuracy at 1MHz it is ±100ppm BNC output connector
***** Destructive/Absolute Maximum Limits Applied to Output BNC***** Absolute maximum current applied to output = 0.2Arms Absolute maximum voltage applied to output = 9VDC or 22VppAC

Input channel
Input impedance = 1M ohm in parallel with 14.5pF AC coupled input (0.15Hz high pass coupled) Maximum signal input = 3.5Vpp maximum before compression (+5dB on graph) Minimum input signal = 100uVpp (-86dB) with Rsource = 50R Noise floor = -86dB at 1MHz/input S/C; -73dB at 1MHz/input O/C BNC input connector
Absolute maximum voltage applied to input = 50VDC or 50VppAC (destructive limits)

Other hardware features

USB connection for data and power USB 2.0 full speed (12Mbps)
Mode led indicating Power and USB activity
Current consumption = 100mA to 220mA depending on activity
Power consumption = 0.5Watt to 1.1Watt depending on activity
Enclosure Ingress Protection rating = IP30
Size = 148mm x 132mm x 43mm – box size including feet and BNC connectors
Weight = 420 grams - box weight, not including the USB cable

Other details

Operating system requirements: Microsoft Windows 98SE, ME, 2000, XP pro with internet explorer 4 or higher
Minimum PC requirements: Pentium II 333MHz, 64Mbytes of RAM, 50Mbytes of free hard disk space, mouse, keyboard, USB, graphics card and monitor capable of 1024x768 resolution.
Advanced graphing program used to display test results
Maximum number of test points = 1000 per plot, 2 parameters per plot
Multiple plots; 10 plots per graph
User text fields
Logarithmic and linear frequency sweep and stationary frequency
Logarithmic and linear frequency axis
User controllable test settling time
User selectable range of frequency points
Logarithmic (dB) Gain/Loss amplitude display
Amplitude display range = +5dB to –86dB (0.025dB best resolution)
Amplitude detector straight line deviation = ±0.35dB
Phase accuracy = see graphs Phase accuracy
Phase range = ±180º and 0º to -180º
|Z| The modulus of the impedance of the test device (DUT)
Impedance accuracy = from ±0.5% to ±4.5% deviation from actual value (see graphs)
Impedance displayed in Ohms or Admittance in Siemens, on a linear/logarithmic axis
Impedance display range of 0.01 Ohms to '1M Ohm' (450K Ohm maximum reading)
Auto ranging or fixed Impedance and Gain axes
Save/Recall as GAD and GZD files
Save graphs as JPEG images, BMP images, Meta files and data files
Use graphs in documents and emails
Graphing Controls; START, STOP, REPEAT, ZOOM, UNDO ZOOM, FULL SCREEN, USER TEXT FIELDS, FREQUENCY LIMITS, SWEEP BACKWARDS, ALTERNATE SWEEP, SWEEP TO ZOOM EXTENTS, PEN COLOURS, PEN LOCK, GRAPH SELECTION, COLOUR/BLACK/BLACK PLUS MARKERS, COPY, CUT, PASTE, MASKS, SCRIPT CONTROL
Calibration option to remove internal amplitude deviations and phase trims
Multiple document operation
Scripting control of the unit

Applications

Measuring the frequency response (amplitude and phase) of systems
Impedance measurement of two terminal networks (including phase)
Design and production testing of electro acoustic transducers
Bio-chemical impedance measurements
Filter design and testing
Battery impedance testing
Cross talk and CMRR measurements

Installing the Software

If the software has previously been installed from the web site, there is no requirement to install the software from the CD. Check the web site for the latest versions of the PC application and embedded code. See the section Software and Firmware Web Updates for details.

Installing the Software from the CD

Warning: do not connect the C60 hardware to the PC with the USB cable before the software has been installed.

Minimum requirements

- Operating system requirements: Microsoft Windows 98, 98SE, ME, 2000, XP professional with internet explorer 4 or higher
- Minimum PC requirements: Pentium 2 333MHz, 64Mbytes of RAM, 50Mbytes of free hard disk space, mouse, keyboard, USB, graphics card and monitor capable of 1024x768 resolution or better.

Installing the software

- Quit all open applications.
- If your computer has auto run enabled, then the software will automatically install. Insert the CD into the drive and the installation will begin. Skip the next instruction.
- If your computer has auto run disabled, then insert the CD into the drive and wait for the operating system to read the disk. Hold the Windows key down and press the R key to open the run dialog box. Type in the following- "#:\setup (enter)", where # indicates the CD drive reference letter.
- The dialog box - 'Welcome to the CyperGraph Setup Wizard' will appear. Click the 'Next>' button.
- The 'License Agreement' box follows. Read it and if it is satisfactory, click 'I Agree'.
- If you already have CypherGraph installed on your PC, then you are prompted to uninstall the existing version (recommended).
- If this is a fresh installation, the 'Choose Install Location' box will appear. The usual location for the software is C:\Program Files\CypherGraph\. Click 'Install'.
- The 'Installing' box will briefly appear, followed by the 'Completing the CypherGraph Setup Wizard' box. Click the 'Finish' button.
- The CyperGraph application will now open. There is no other action needed, other than to remove the CD.
- Keep the CD in a safe place, for future use by you or your colleagues.
- The C60 can now be connected to the PC via the USB lead. This will be the first time that the C60, a USB device, has been registered with the computer. What happens next will depend on which version of Windows is running.
- Windows 98 and ME will automatically install the device driver without action on your part.
- Windows 2000 will open the 'Found New Hardware Wizard'. Click 'Next>'. On the next dialog box select 'Search for a suitable driver for my device (recommended)', which will complete the installation.
- Windows XP will open the 'Found New Hardware Wizard'. Check the radio dial labeled 'No, not this time' and then click 'Next>'. On the next dialog box check the radio dial labeled 'Install the software automatically (Recommended)' and click 'Next.' On the third dialog box click 'Finish' to complete the driver installation.
- Check the web site for the latest versions of the PC application and embedded code. See the section Software and Firmware Web Updates for details.

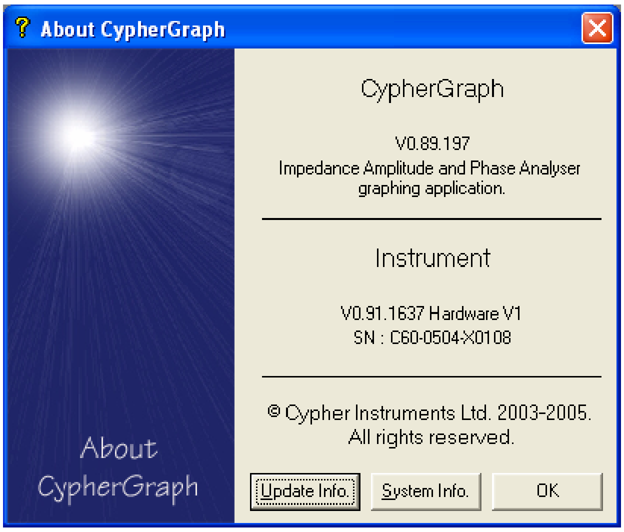
Uninstalling the software

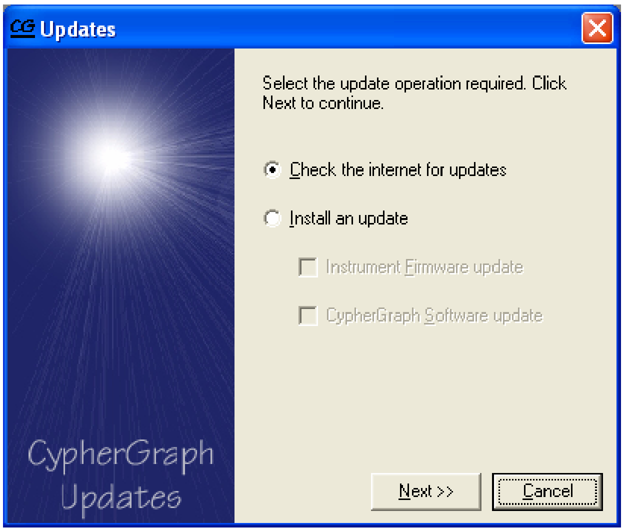
- Navigate to the Control panel. Go to 'Add or remove programs'. Left click on 'CypherGraph'. Right click on 'Remove'.

See Appendix D for further software and device driver installation details.

Software and Firmware Web Updates

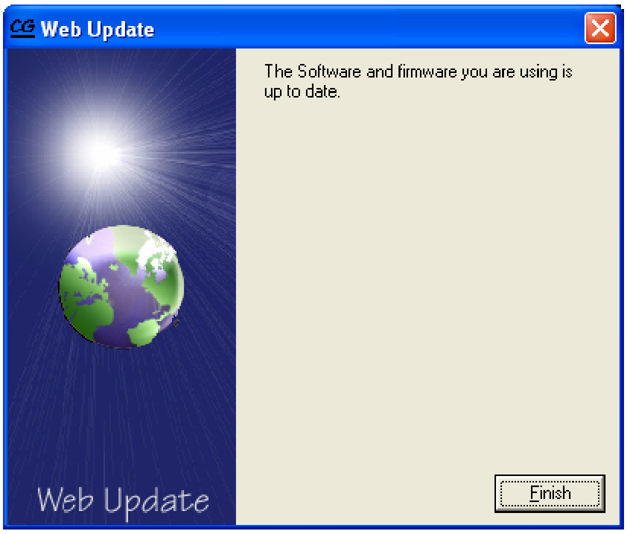
Periodically the PC software or Firmware of the instrument may be updated to add new features or fix bugs. The Update Info. button on the About CypherGraph dialog provides the method of downloading and installing software and firmware updates. From the **Help** menu select the **About CypherGraph** item. Click the 'Update Info' key and then click the 'Next>>' key to check for available updates.

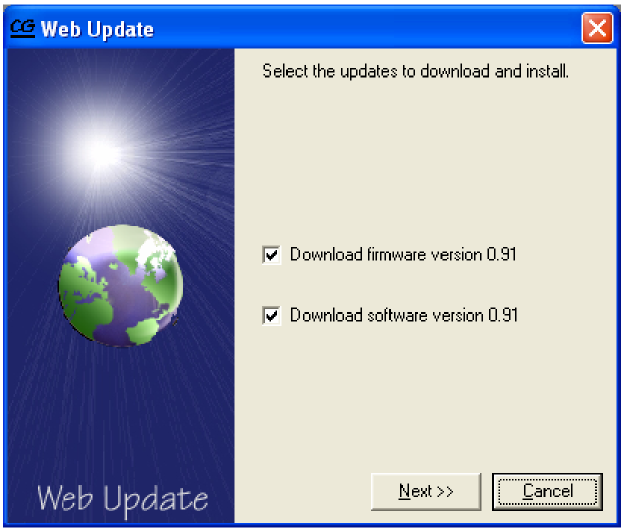




Select the 'Check the internet for updates' dial. This only works if the PC has internet access.

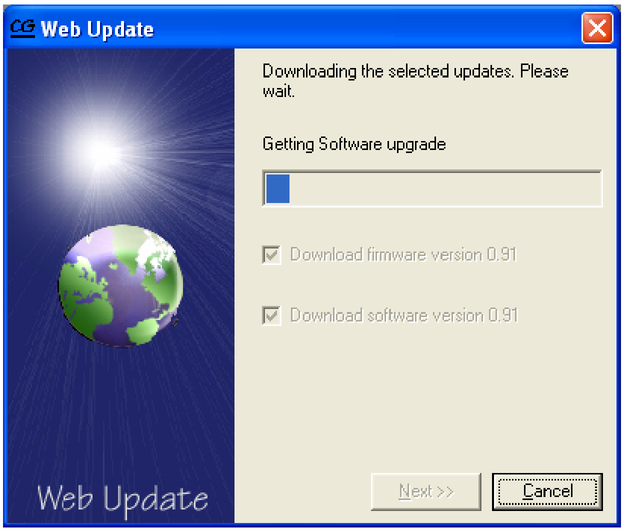
If the software and the firmware are up to date, then you will be prompted to leave. Otherwise, select the firmware and software that you want to download. It is usual that both the software and the firmware updates will be available. CypherGraph will only check for firmware updates when the instrument is connected.

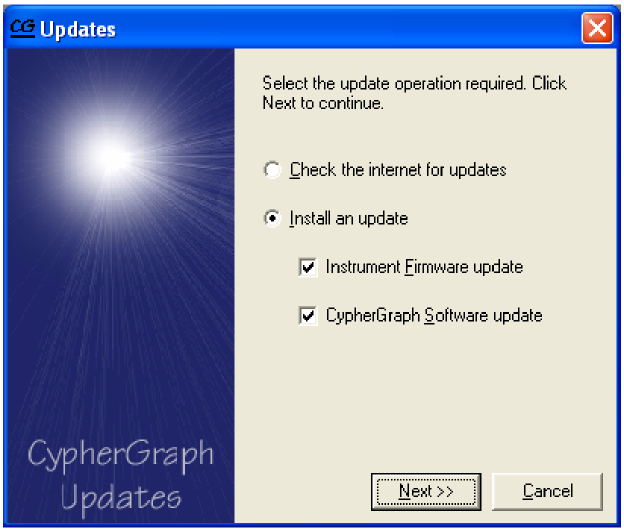




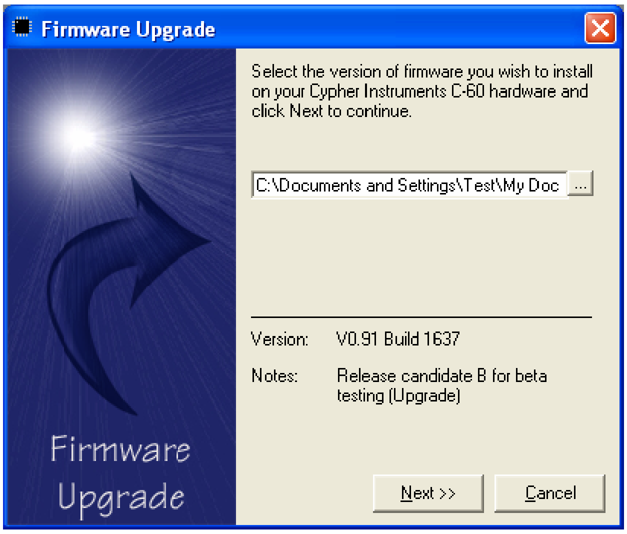
Click the 'Next>>' key.

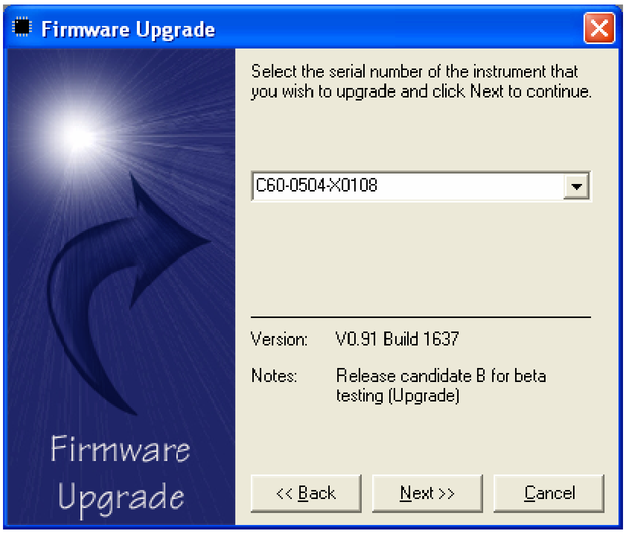
Data will now be downloaded from the web and a blue progress bar will *entertain* you. In this example, both the software and the firmware are downloaded from the web.





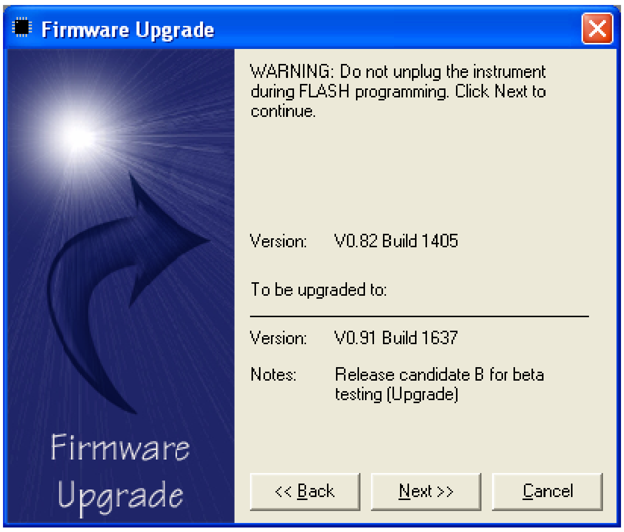
When the download is finished, you are asked to install the new firmware code into the internal processor of the C60. Click 'Next>>'.

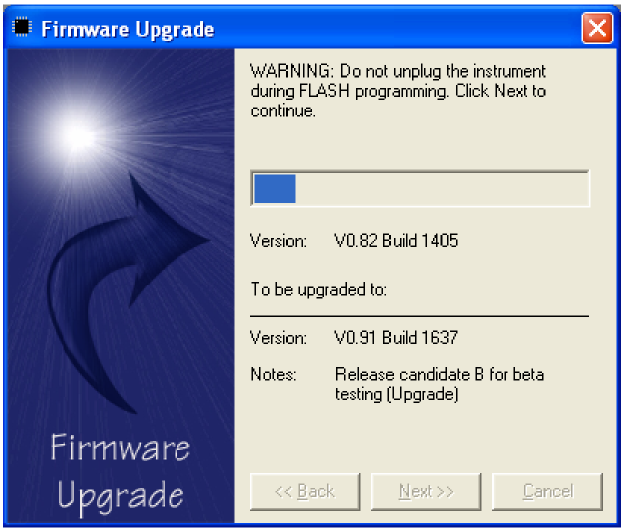


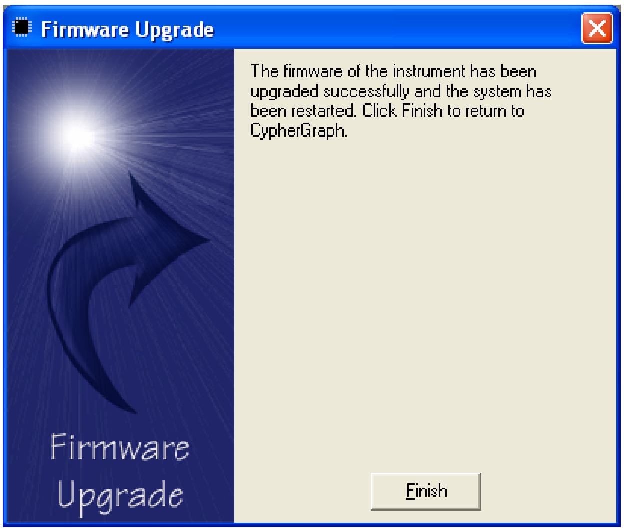


Choose the serial number of the instrument that you want to upgrade. Usually there will only be one unit connected.

A 'WARNING' states that the upgrade process will not take kindly to being unplugged during this installation procedure. The C60 has the capability to upgrade the firmware which is stored in FLASH memory. The original shipped firmware remains write protected, but the remainder of the FLASH memory can be re-written by the host computer. Upon reset, the original shipped firmware is run. This firmware determines if a newer version of code is present by using a CRC check. If the newer version of firmware is found to be correct, execution transfers to this code. This method prevents an unrecoverable system crash that can occur if a new program download is interrupted or corrupted. Click the 'Next>>' key and hope that there isn't a power cut.

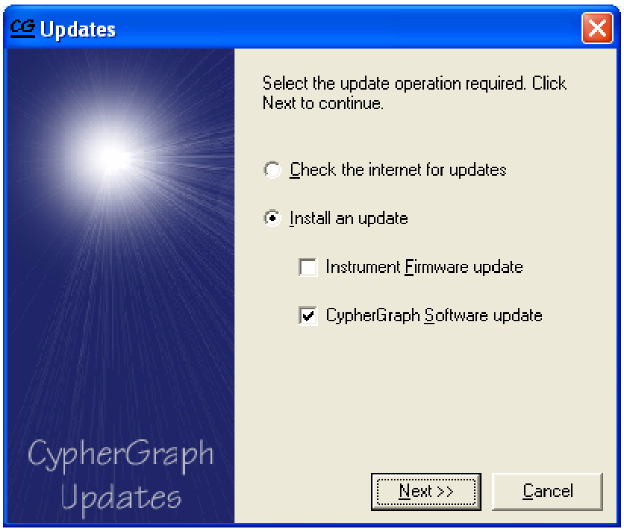


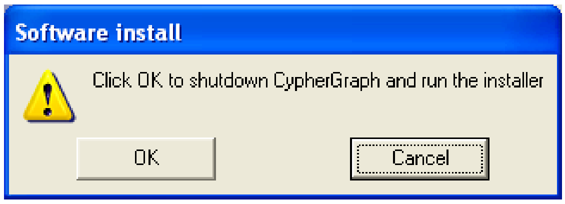




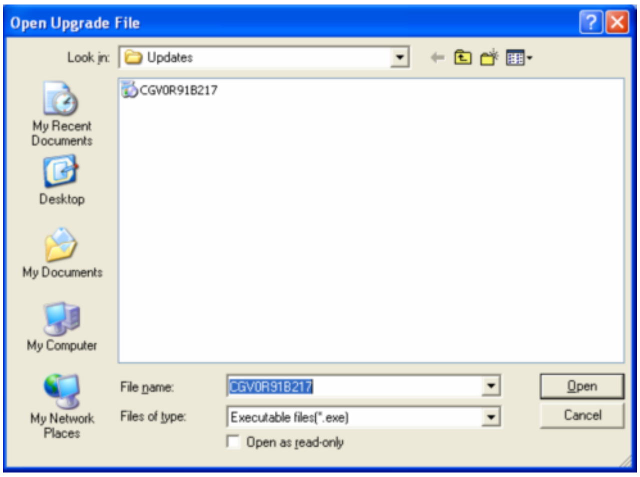
When the upgrade has been completed, click the 'Finish' key. The firmware has been modified and has been installed inside the C60.

Now, install the CypherGraph software. This is a PC program. Click 'Next>>' and then 'OK'.



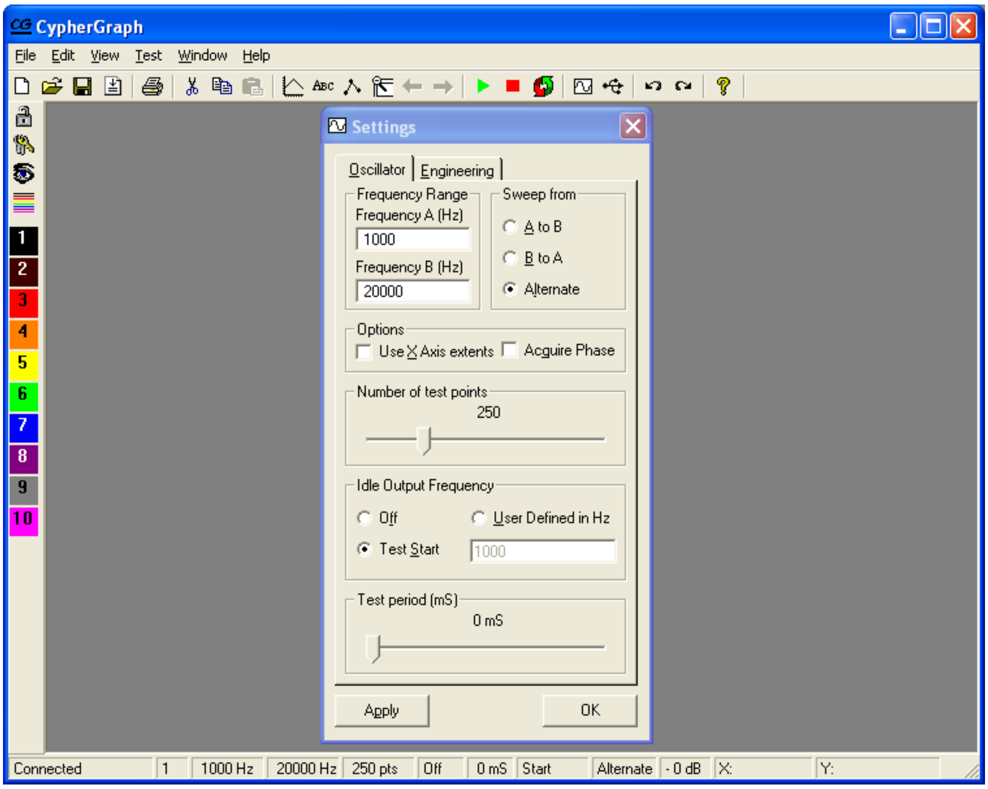


Select the most recent file date and click 'Open'. This takes you to the CypherGraph Setup Wizard. Click 'Next>'. For details of software installation see Appendix D.



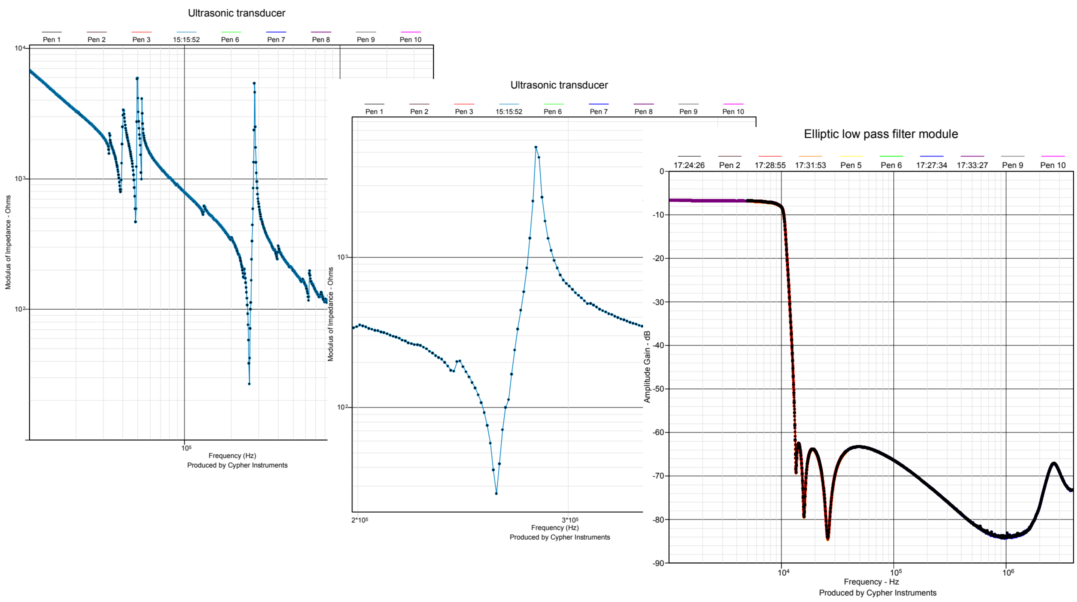
Using the CypherGraph Software

When the application is launched, a blank start up page is produced. If the device is not connected, then tests cannot be performed, but existing graphs can be viewed. With the C60 connected, new graphs can be produced and existing graphs can be viewed. The blank start up page is shown below. The Settings dialog box will appear if a unit is attached.



The three boxes on the top right hand side are **Minimize**, which places the application on the task bar; **Maximize/Restore down**, which controls the screen size of the application and Close, which turns off the program.

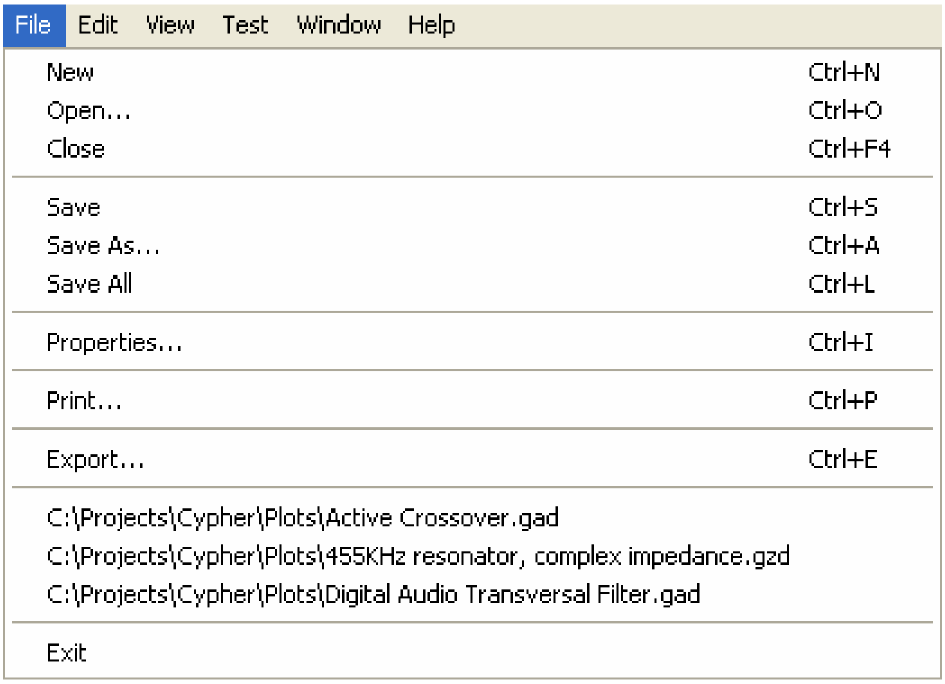
The following text describes the menus and tools (in tedious detail), however for instant gratification, jump to the section titled Viewing a graph, where as it suggests, you can view the example graphs that are supplied with this product.



Menu Bar

The row of text is called the **menu bar**, the function of which is described next.

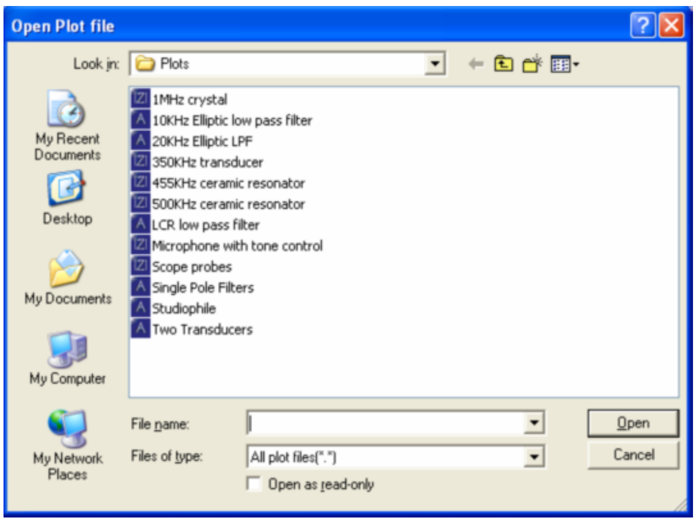
File



The File handling drop down menu allows the user to open existing files (graphs), investigate file properties, create new files, save, print and export them. Note that the commands in this menu can also be initiated by control characters. For example, Ctrl+N = New File.

New starts a new file, which can be Amplitude or an Impedance response.

Open… takes you to the Plots folder, where files (graphs) are stored. Double clicking on a file will open it. There is a choice of plot file extensions; *gad* which is the amplitude response format and *gzd,* which is used for impedance responses.



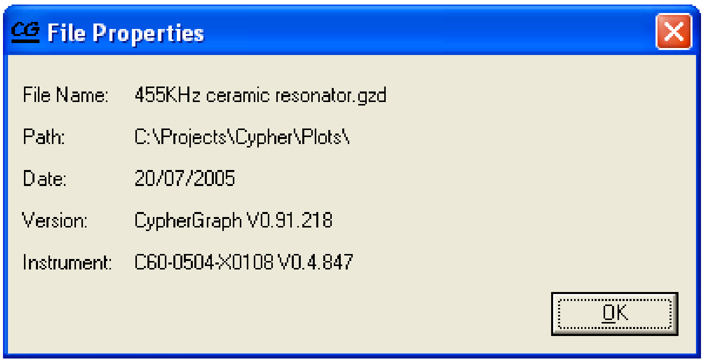
Close finishes work on the current file.

Save stores the current file in the Plots folder. Hint, don't use either / \ (slash) in the graph title and CypherGraph will suggest this as the file name.

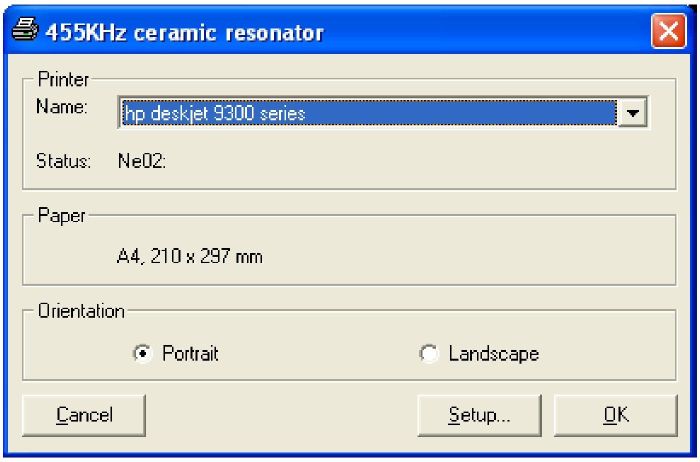
Save As… stores the current file with the option of choosing a new file name

Save All stores all files that are open in the application.

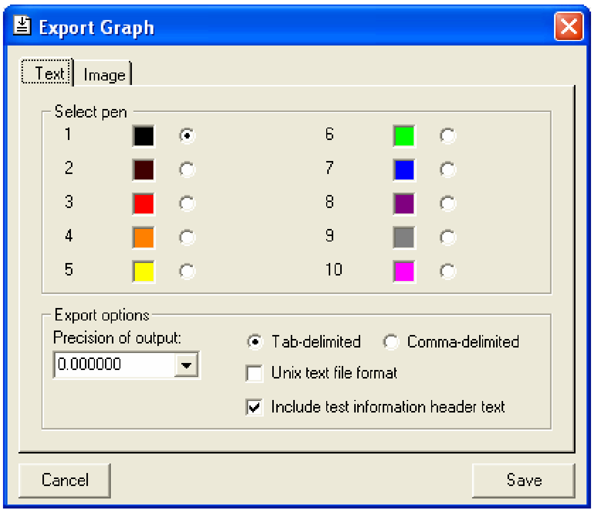
Properties... shows the properties of the graph that is currently in focus. This information includes the file path, size, and date of initial creation. Also shown is the version number of the PC software, the embedded code version number and the hardware serial number of the C60 used at the time of creation. If an old file is reused with different hardware and software, the File Properties do not reflect these changes.

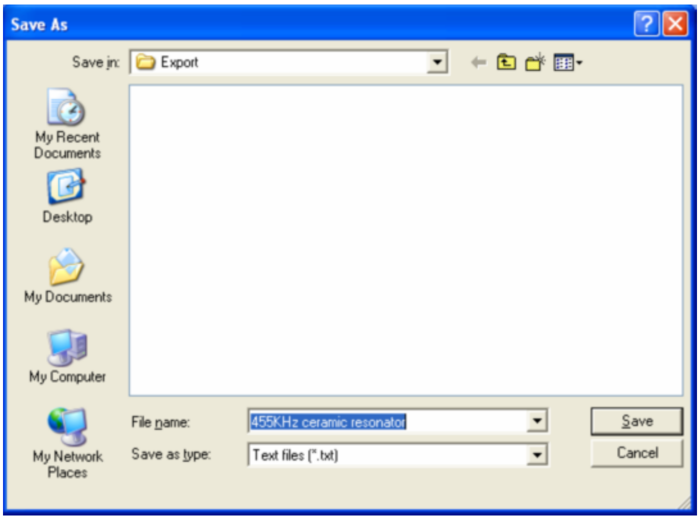


Print... enables graphs to be printed directly from the application. The best print quality is obtained by this method. Colour, Monochrome or graph markers can be selected in the Graph View Options dialog as shown in [The Graph View Options](#) section. The Setup... button takes you to the dialog box for the installed printer, so that the paper size and orientation can be chosen.

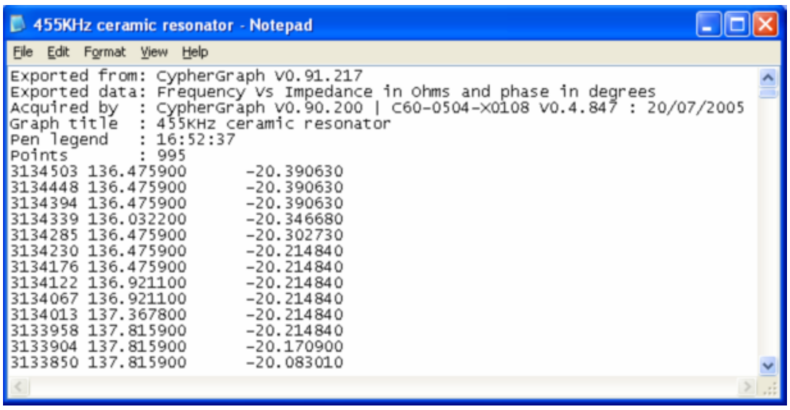


Export... can generate data files for use in other programs. From the Text tab, select the individual pen plot that is to be exported. Next, press Save and enter the file name. Note; <u>only one plot at a time is exported, not the whole graph.</u>



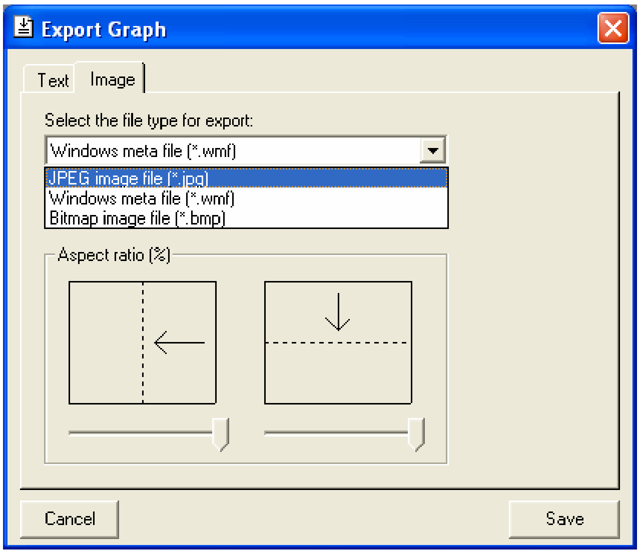


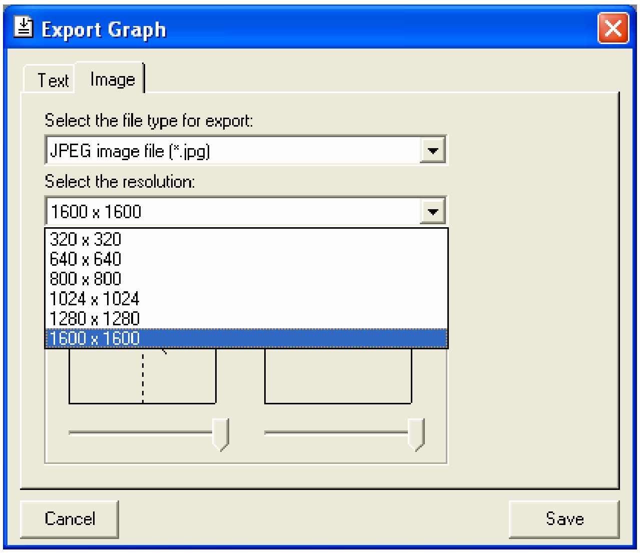
The Text file contains the data that is used to draw the individual plots. The file can be opened and edited with Microsoft's Notepad and can also be used by other graph plotting programs.

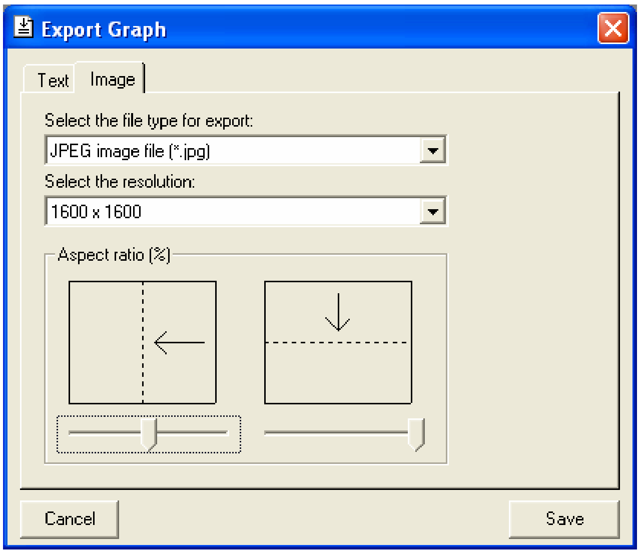


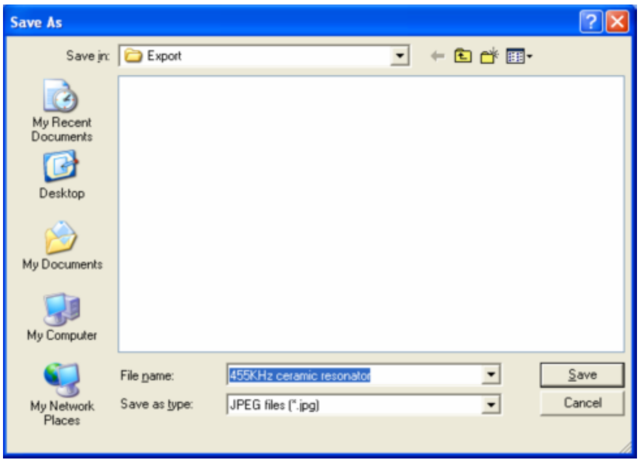
CypherGraph also produces image files. These formats are JPEGs, bit maps and meta files. These are useful if you have to include the graphs in other documents. Generally the meta files give the best image quality.

First select the image file format. If you want good quality JPEG graphs, then choose a high resolution. Next change the aspect ratio as desired and then Save the file, renaming it if needed.

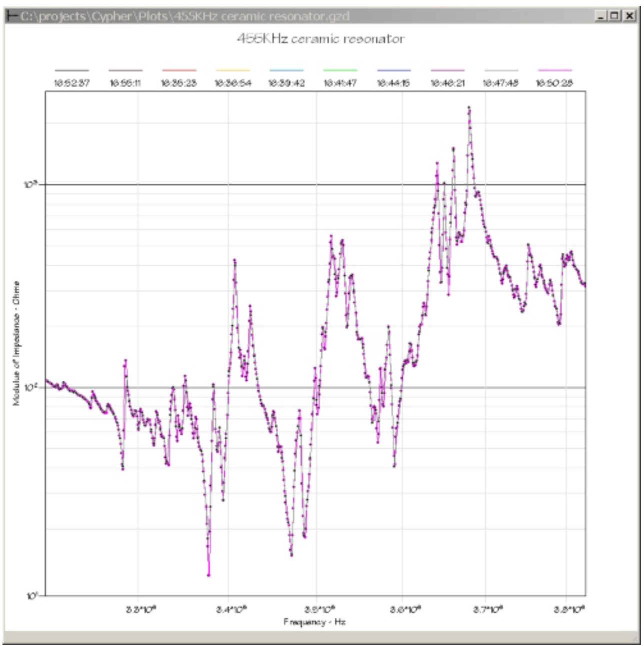






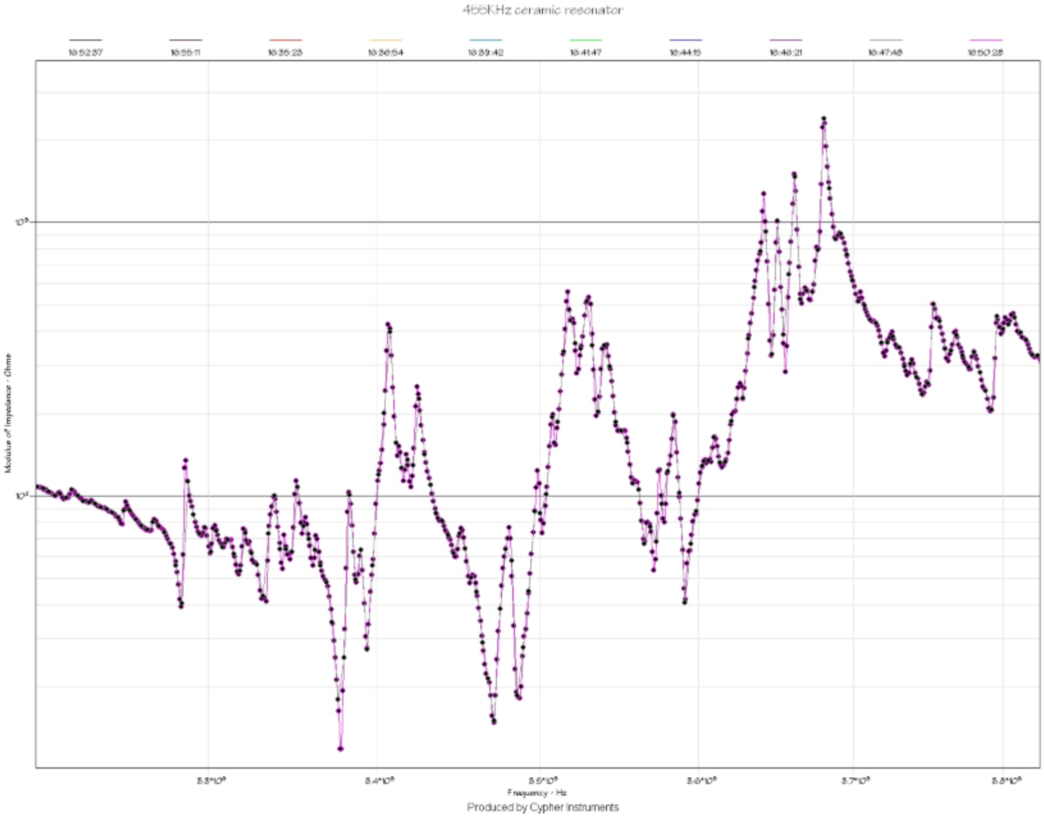


There are many properties associated with file formats and file sizes. The following pictures are all the same graph. The graph on the right is a screen capture which was saved as a JPEG file. This is not an Export Image feature of CypherGraph. The file size is 178k and is dependant on the screen image resolution of the PC.



When Export Image is applied to the same graph, with a 1600 X 1200 resolution, the files sizes are;

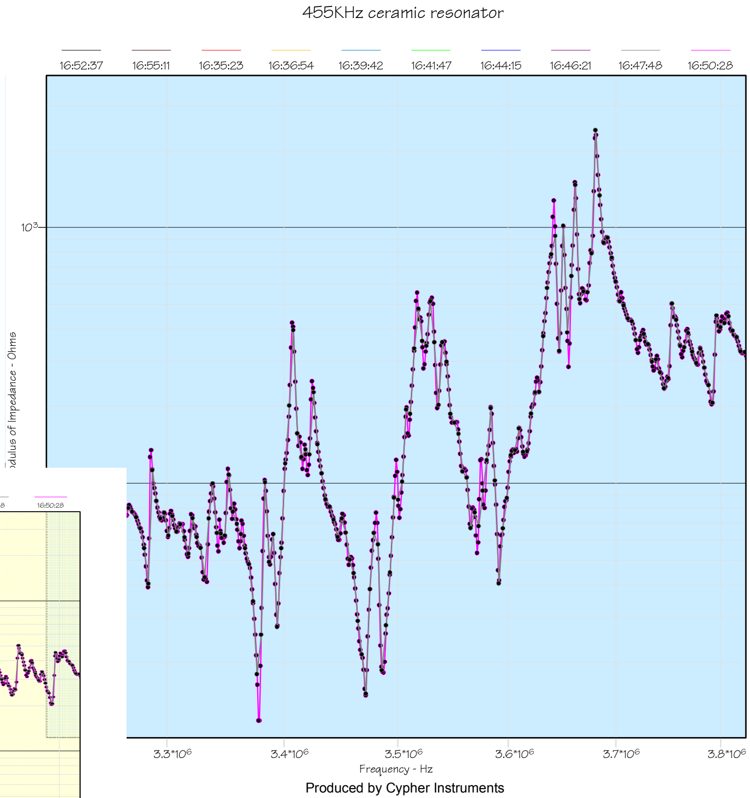
*.JPG = 398k
*.BMP = 7,501k (massive)
*.WMF = 130k

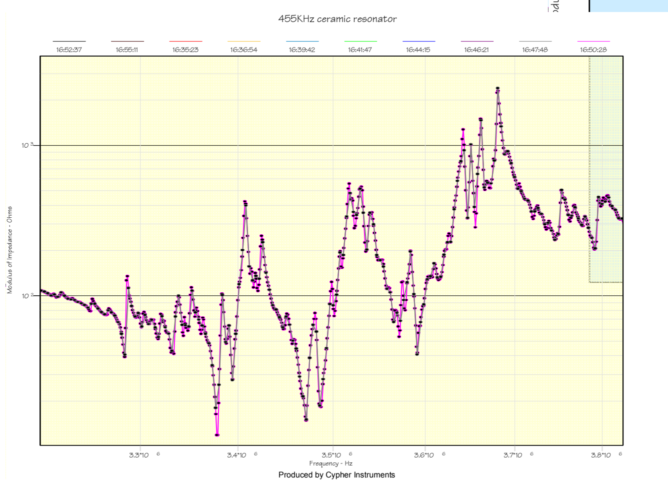


The top picture is the Export Image JPEG output, with an aspect ratio of 1600 X 1200.

The Export Image BMP output file is so massive (7.7Mbyte which is bigger than the size of this manual) that it was not included in this document.

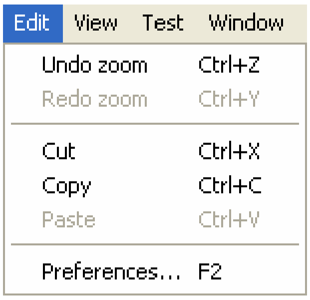
The WMF metal file (large middle and small lower) is the smallest of these outputs. It produces a good graphical image and has good resizing, stretching, colouring and transparency controls.





Exit closes the application.

Edit



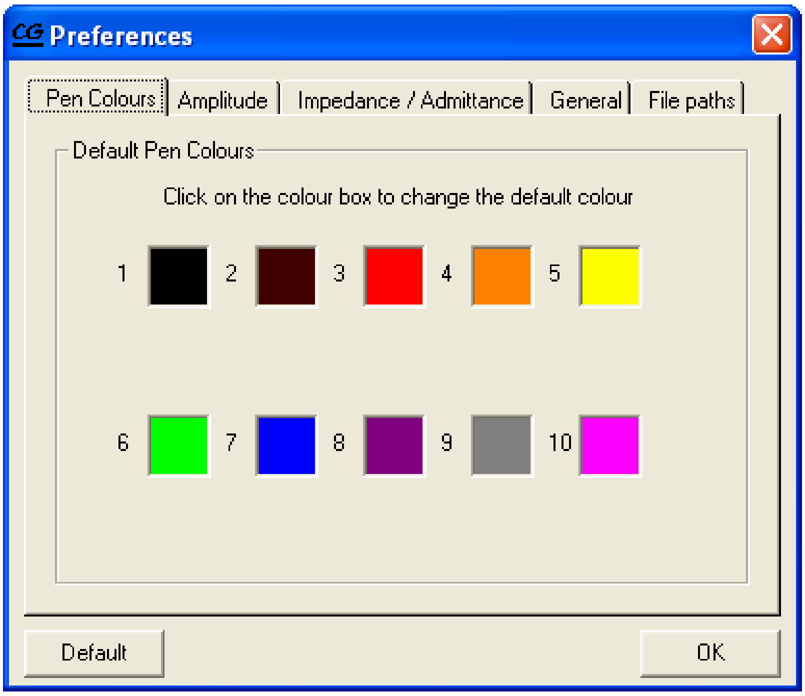
Undo zoom steps backwards through the graph Zoom history. There are some aberrations in this process, but it does get there.

Redo zoom steps forwards through the graph Zoom history.

Cut, Copy, Paste allows the user to Cut or Copy a plot from one file and to Paste it into another. These files must have the same file extensions.

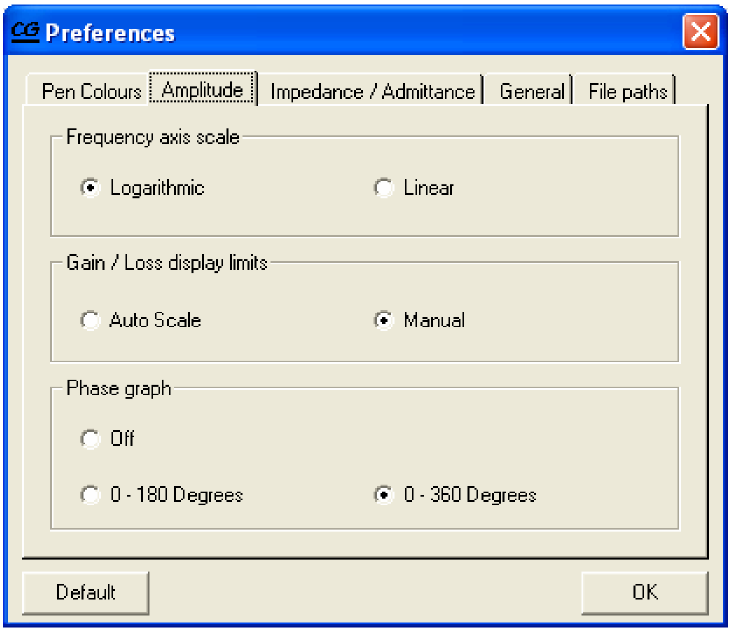
Open two files. Click on the first graph and then select a pen number by clicking on one of the ten pen colours. This is the pen plot that will be copied. Press **Ctrl+C** to Copy it. Now click on the second graph. Select a pen number that has not been used. Press **Ctrl+V** to Paste the plot into second graph. This is a very powerful method of editing and transferring plots. Cut (**Ctrl+X**) can also be used as a direct method of deleting a plot in a graph.

Preferences... enables the user to customize some of the features of the application. Select the Pen Colours tab and then double click on a colour box. This launches the Color dialog box which is used to define the pen colour from a Basic selection or a Custom Colour range.

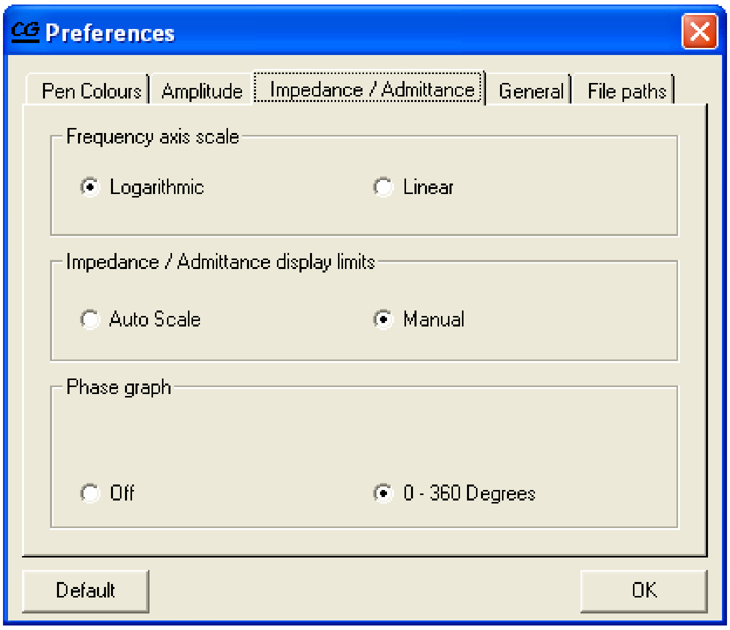


Use the preferences box to set up the default view of the graph.

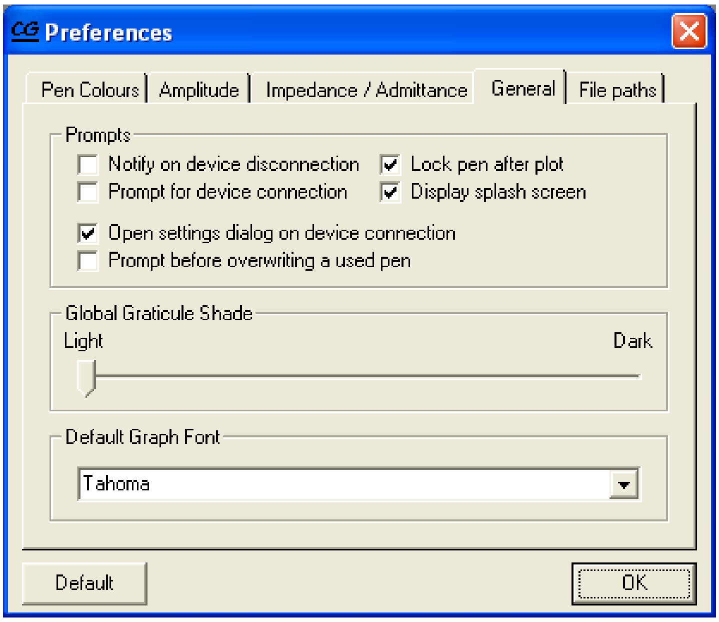
The Amplitude Response tab sets the Frequency axis to be Logarithmic or Linear, sets the Amplitude Scale range and controls the settings of the Phase graph.



The Impedance/Admittance Response tab sets the Frequency axis to be Logarithmic or Linear, sets the Impedance/Admittance Scale range and controls the settings of the Phase graph.



The General tab has a selection of user preferences. The pen selections are worth considering. These can be set to overwrite a plot, which could result in loosing valuable work! To avoid this, pens can be locked after a plot has been performed. Control of the minor graticule shade is provided here.



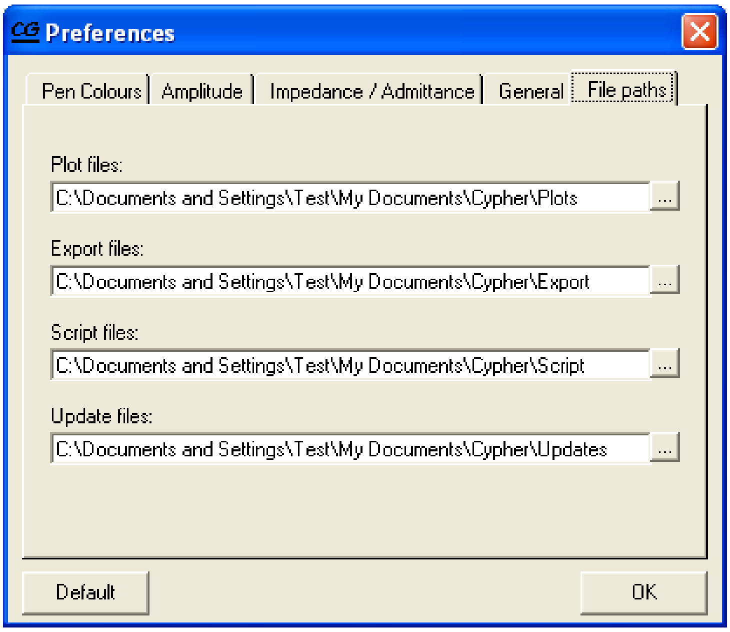
The files associated with CypherGraph are stored in four folders.

\Plots - GAD & GZD files are the Amplitude and Impedance graphs.

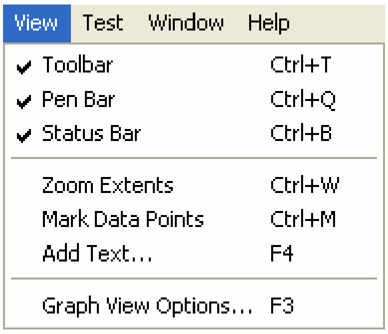
\Export – data, BMP, JPG and WMF files are stored in this folder.

\Script – is a programming language that drives the hardware. This is useful for automated applications.

\Updates – for the PC application and the embedded code are held here.



View

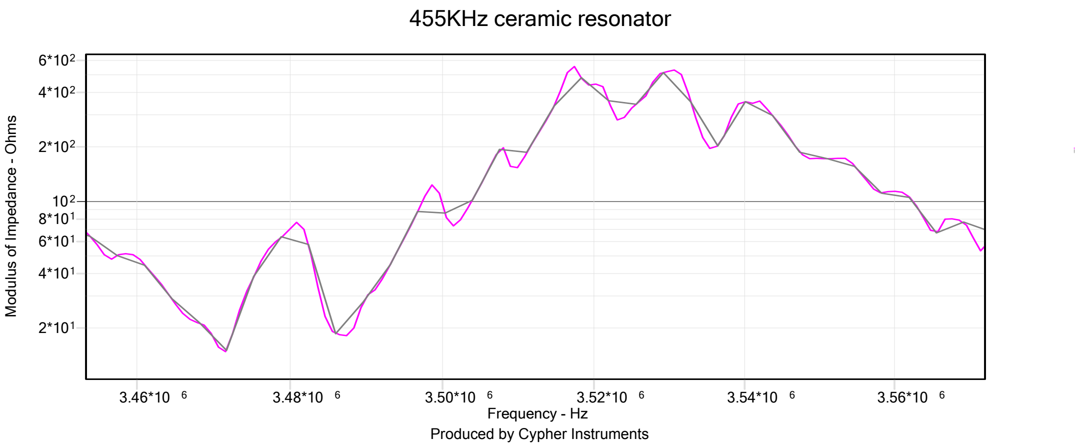


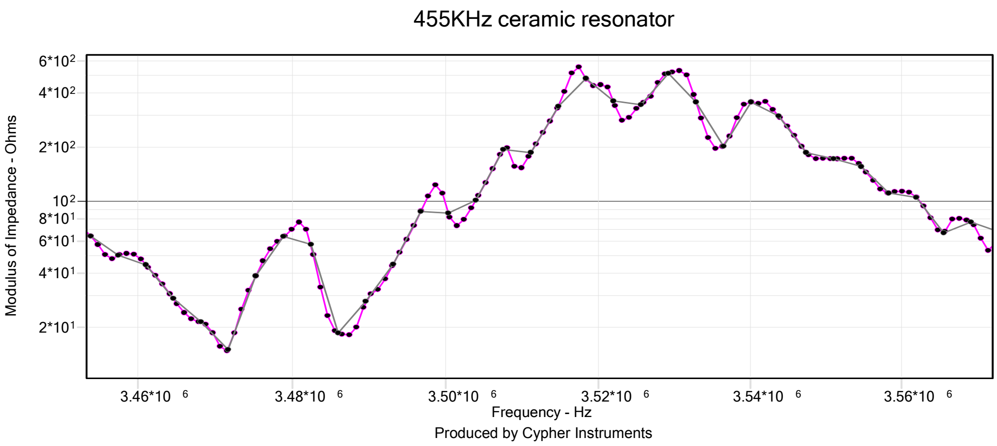
The View menu controls the general view of the application and the graph.

Toolbar, Pen Bar, Status Bar turn on and off these Bar displays. This in turn affects the screen area that is available for graphs.

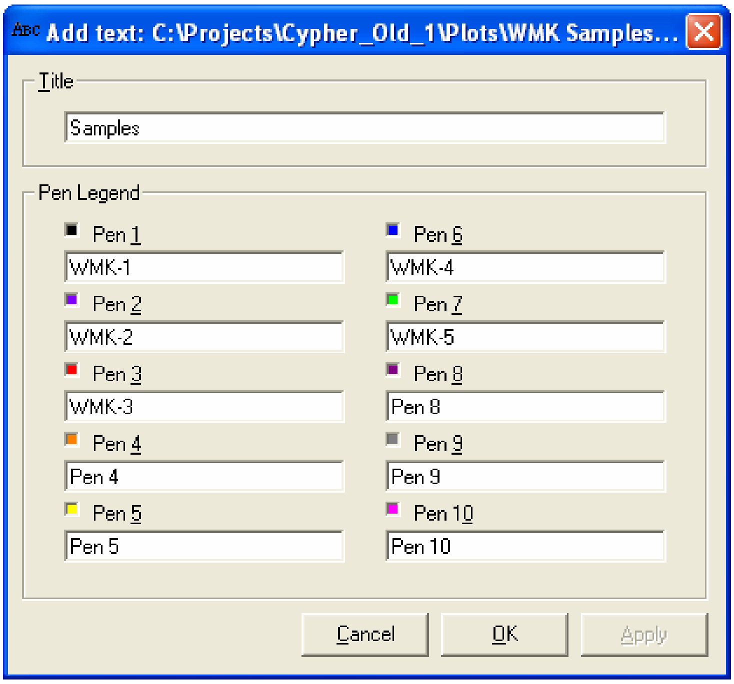
Zoom Extents maximizes the horizontal and vertical range of the graph that is currently in focus. This includes the phase graph if it was active.

Mark Data Points inserts solid markers on the graph (toggle action). These markers indicate the location of test data points. Some flat plots can be obscured by the graph axis marks. Other plots have such dramatic transitions that they are not visible on a maximized graph (see 1MHz crystal.gzd). Only when the Mark Data Points function is active, are some plots are visible. Also, this function is useful for revealing under sampling problems. In the following two graphs, the black and mauve plots are impedance plots of the same ceramic resonator. Marking the data points reveals that the black plot is heavily under sampled. It misses most of the response curves. Even the mauve plot needs more sample points.



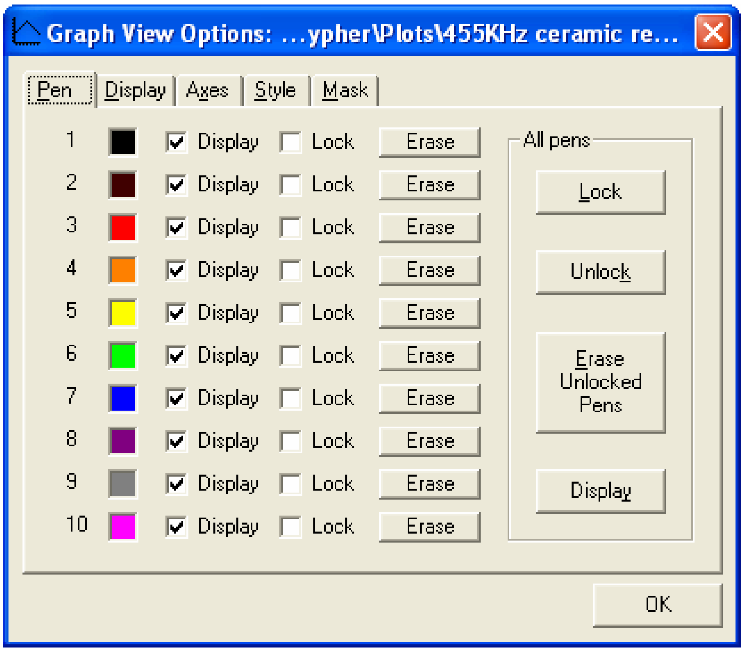


Add Text allows the user to annotate a graph. The graph title can be edited, as can each of the 10 plot legends. Pens that are not titled by the user are time stamped (hh:mm:ss). The font & size can be selected from the Graph View Options dialog box.



When a graph is saved, the program will suggest that the 'graph title' is used for the file name. This is a self documenting process. However, if any of the following characters are used in the title – (/,\.,:,*,”,<,>,|) the user will have to manually enter a file name containing valid characters.

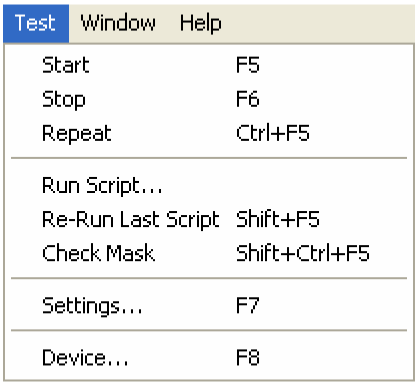
Graph View Options selections can be obtained from this menu. This dialog box can also be accessed by right clicking on the graph. The plots can be Locked, Unlocked, Erased and Displayed or hidden, either individually or as a complete block.



When a graph contains many plots, it becomes difficult to identify each one. By clicking the Display box, a plot can be made to identify itself.

For a detailed explanation of the graph view options available see The Graph View Options section.

Test

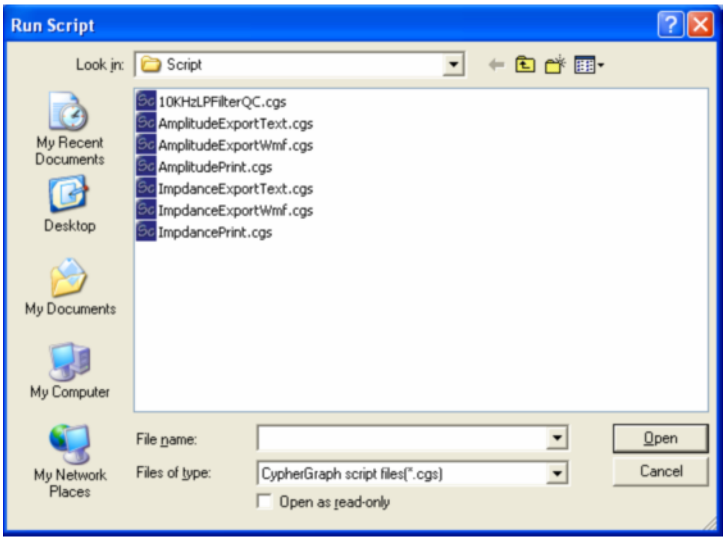


Start, Stop and Repeat are commands that control the hardware. These commands are also available from the horizontal tool bar.

Start causes the C60 to perform a frequency sweep test, the results of which are used to generate a pen plot. At the end of a sweep, the pen number is incremented.

Stop terminates any test that is currently in progress. The system does not have a pause feature.

Repeat puts the unit into a repeat sweep mode. In this mode, tests which have been started continue endlessly until they are stopped. Plots on the graph are over written when the pen counter revisits them. However, pens can be locked to avoid this (see Graph View Options).



Run Script... enables the user to control the C60 from a script file. Instead of typing and pointing and clicking with the mouse to perform a test, the user can run a previously written list of commands. This allows the user to create tests that can be opened and run, enabling repetitive usage. The script language is detailed in Appendix C of this document.

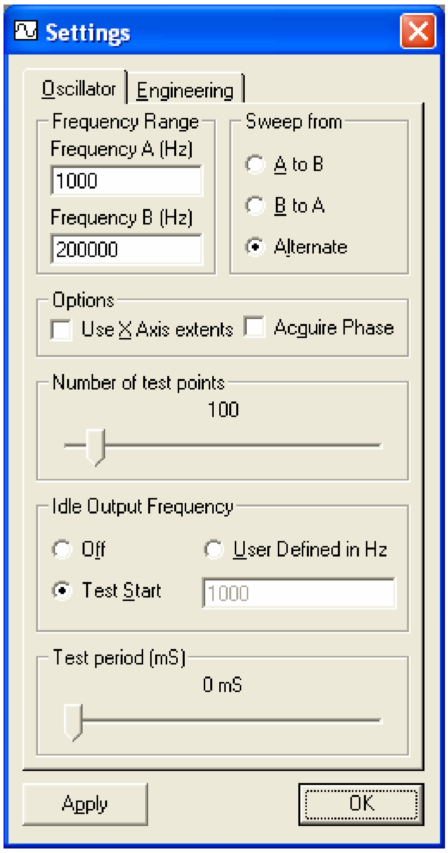
A non document text editor is used to edit the scripts and error checking traps gross mistakes. The script file is sent to the C60 where it resides in non-volatile memory. This provides the user with the facility to configure an instrument to perform a set of tests for a particular application. The user then need only to connect the device to the PC and Re-run the last test script. In combination with the C60's digital control outputs this makes the instrument particularly suited to production test and quality control applications.

For details of the scripting language see Appendix C.

Re-Run Last Script repeats the last Script run by the instrument.

Check mask compares the plot against the graphical masks. First select a pen from the pen bar. Then select Test - Check mask. The selected plot will then be tested to see if it is inside the mask and a dialog box will declare the test result.

Settings control the C60 electronics. The Oscillator tab of the Settings dialog box controls the sine wave test generator. The oscillator sweep range is from Frequency A to Frequency B, or B to A, or Alternate. This last setting is very useful for the Repeat mode. Frequencies are entered numerically and scientific notation (1k523 or 0.774M) can also be used. Click the Apply button to **enter** the data.



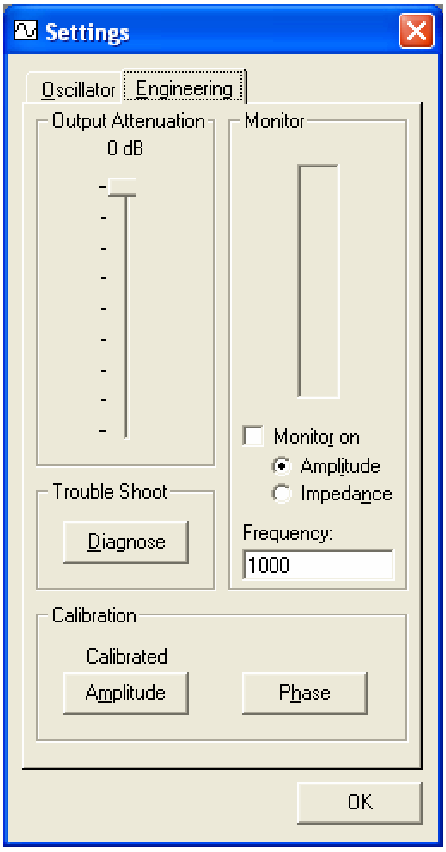
The sweep range can also be controlled graphically by checking the X Axis extents box. This uses a Drag & Zoom function to define the sweep range. If say, there is an interesting section in a plot, then zoom into it and the next test will use these zoom limits to perform the sweep.

The number of test points is set by a slider. With 1024 test points, the graph has maximum resolution, but takes a long time to generate a plot. The minimum number is 24 points, which allows the user perform a quick test.

The Idle Output Frequency can be set to be Off (no output signal), or On, at a frequency set by the User or the Test Start value. Choose Test Start for Repeat mode. Extra time delays can be added to each test point using Test period slider. This allows systems under test to stabilize.

Most parameters are applied at the end of a test, although the Number of test points slider is active all of the time.

The Engineering tab provides control of the sine wave output attenuator. The output range is 0dB to -20.0dB, selectable in 2.5dB steps. Best results are obtained by using a maximum level test signal. The C60 has its own dynamic range issues and the use of low signal levels will degrade performance. In the Amplitude response mode, the C60 is designed to test systems with very little gain and lots of attenuation. If the device under test (DUT) has a significant gain (X dBs for example) then use a low impedance attenuator of X dBs at the input of the test device.

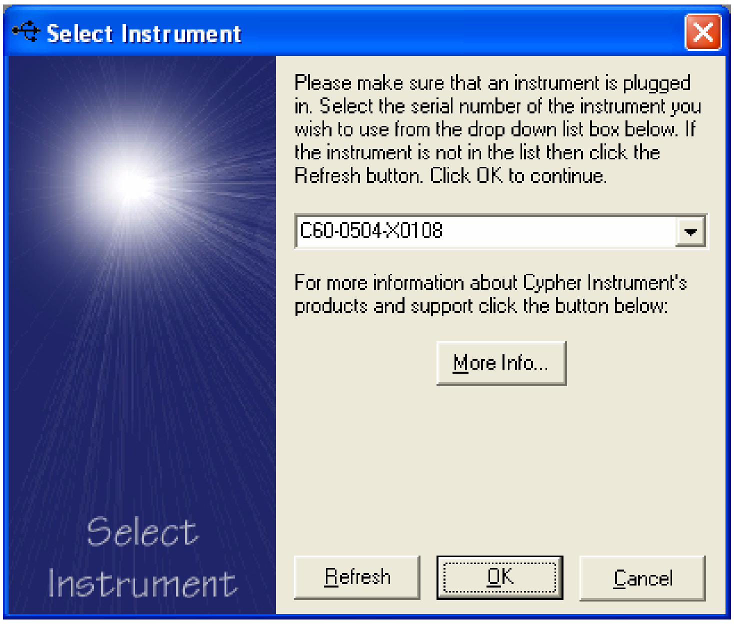


The Monitor bar displays the input signal Amplitude or the 'output' DUT Impedance when the Monitor box is checked. This is used to monitor the Amplitude or Impedance before a test. It is not active during a test. The test frequency can be set manually.

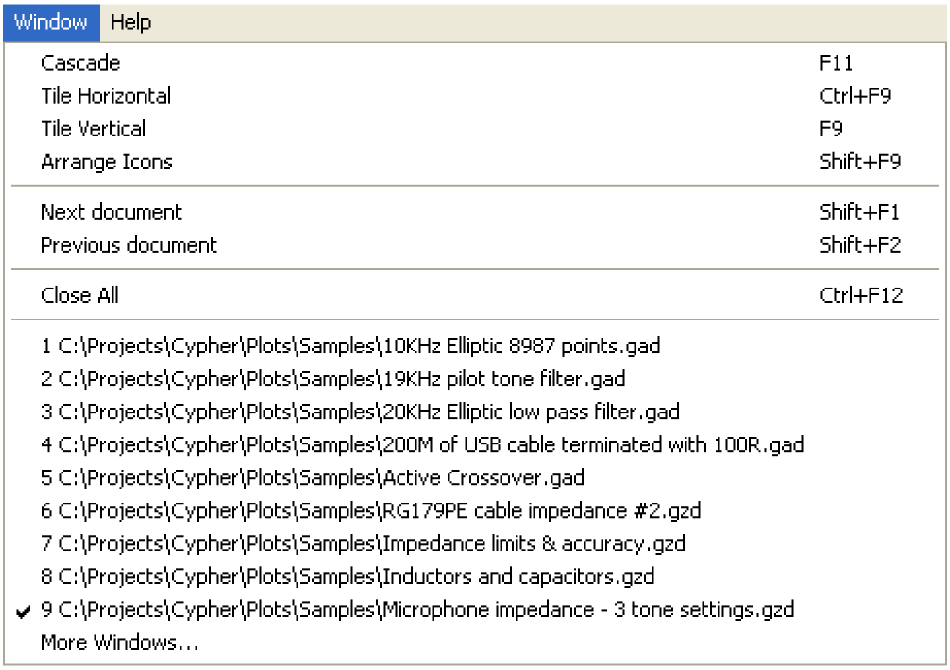
The Diagnose key generates a self test graph. It displays the previous calibration curve, the attenuator steps and the amplitude slope. This graph is useful for remote fault diagnosis.

Calibrate Amplitude tests the amplitude flatness of the C60 and applies a correction curve to plots. **This process takes a long time.** The user should recalibrate regularly. Phase calibrates the internal phase trim electronics. This process is performed automatically by the instrument. When the phase calibration is performed a graph is produced allowing fault diagnosis to be conducted remotely.

Device opens the Select Instrument dialog box. If there is more than one unit connected, then choose which one to use. The instrument's serial number is displayed. If there is only one instrument plugged in to the PC then press **F6** to connect.



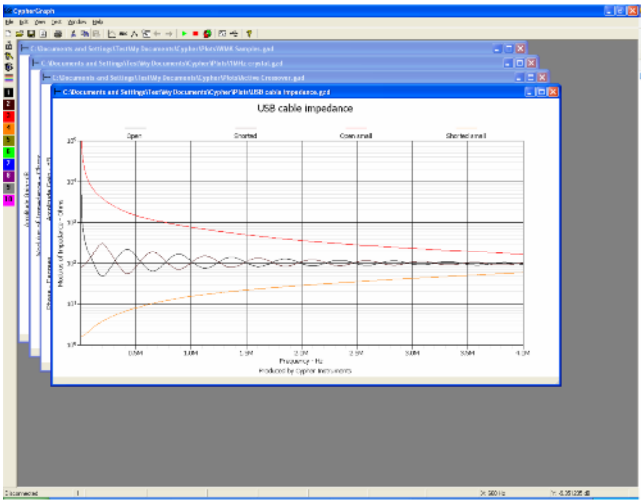
Window

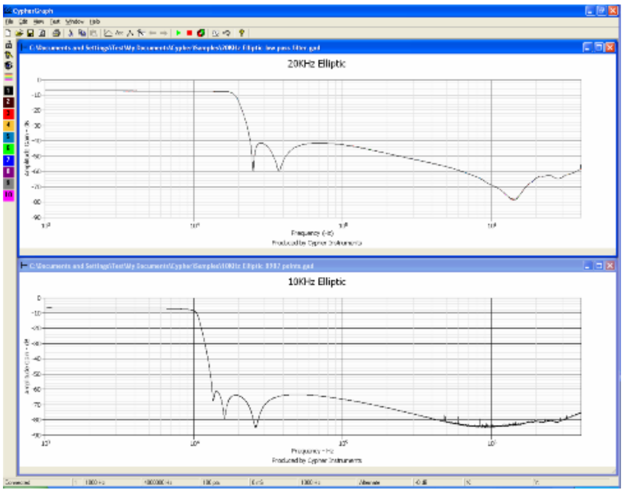


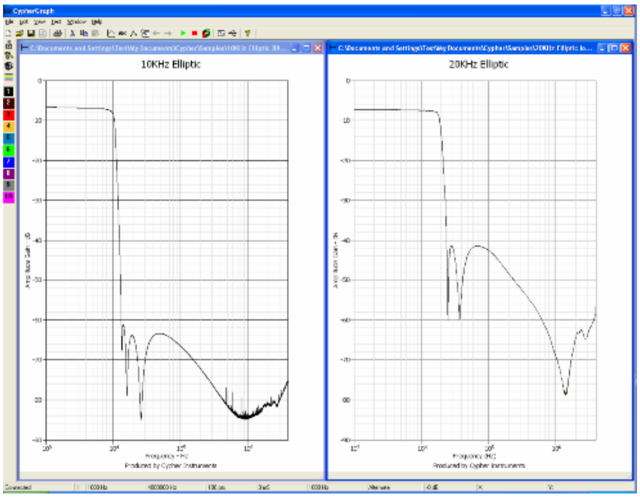
The window menu provides control over the graph document windows. Alt + W followed by a number 1 to 9 provides quick selection of the first 9 document windows. Further documents may be selected through the **More Windows...** dialog. **Next document** and **Previous document** cycle through the document list.

When there are multiple graphs open, **Cascade** produces a cascaded display of graphs. Only the top graph can be seen, but the others are placed in focus by clicking on the blue bar at the top of their box.

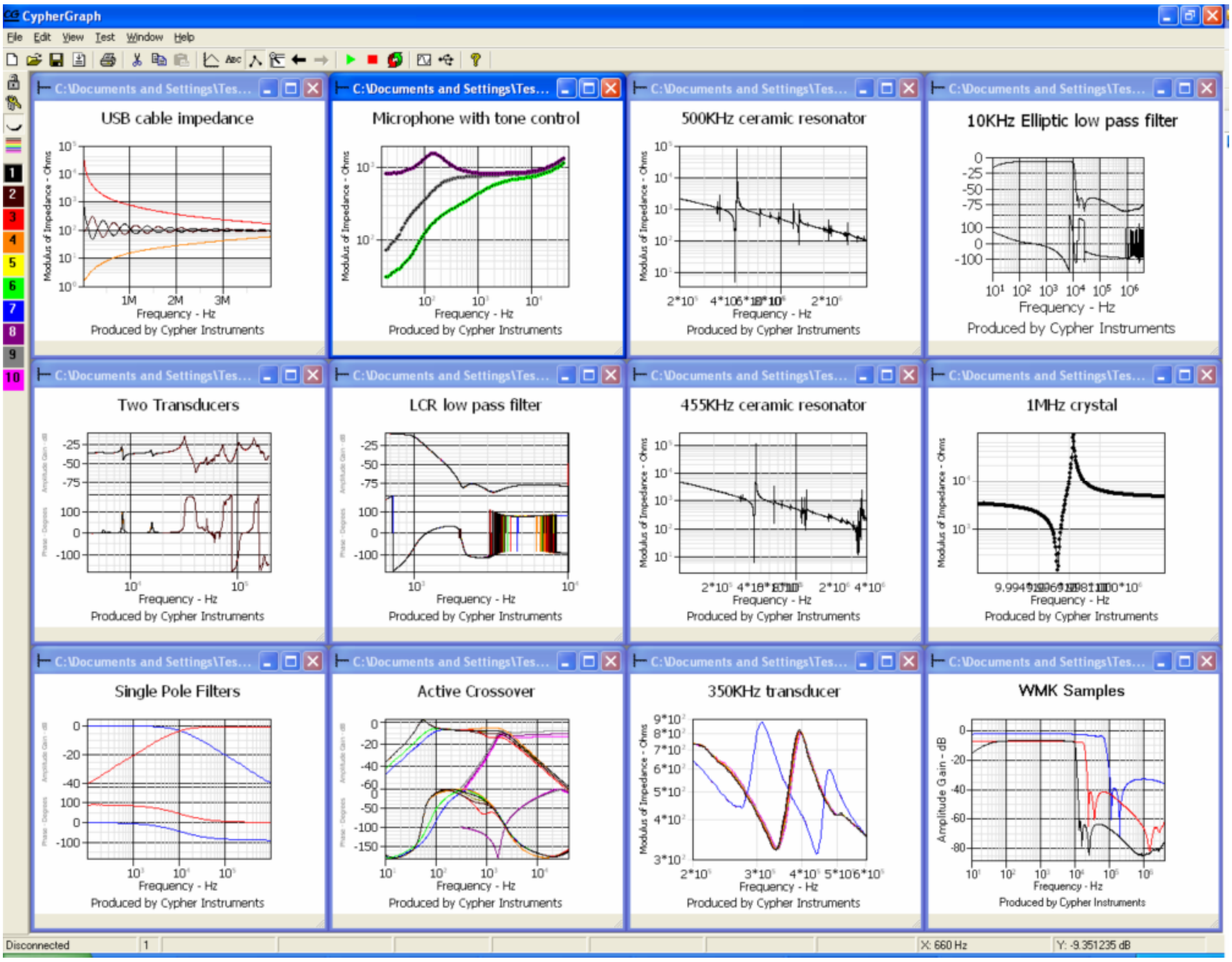
Tile Horizontal and **Tile Vertical** enable all graphs to be made visible.







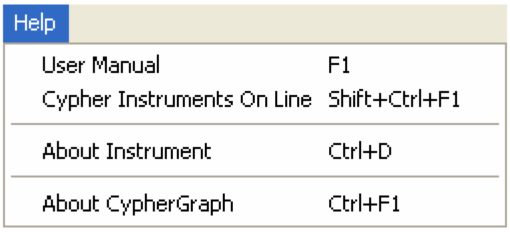
As more and more graphs are displayed, their size is reduced. There is no limit to the number of graphs open. The limitation is one of screen resolution. Eventually, the graph and text is so diminished that it serves no purpose having it on the screen. Even with many graphs open, the one that is in focus can be used to perform tests.



Arrange Icons is used to organize graphs/icons that have been minimized.

Close All removes all graphs from the screen. If they need saving, then a prompt dialog box will appear

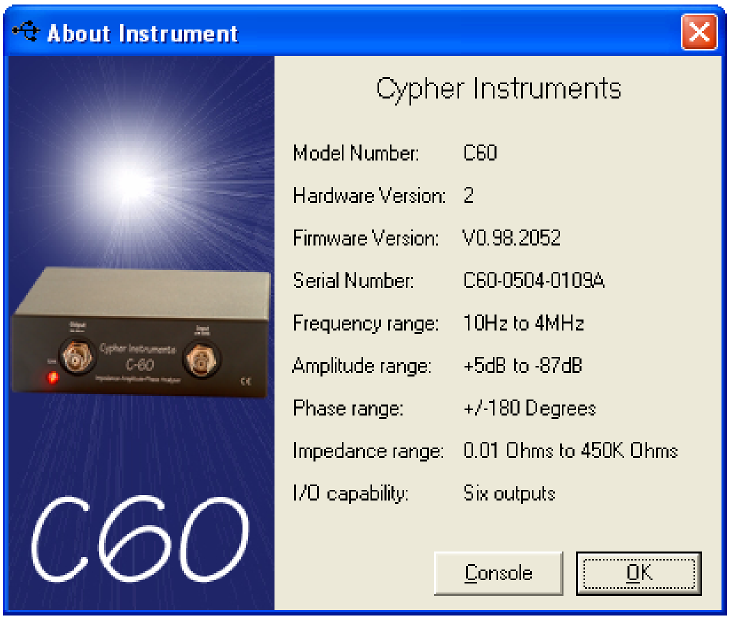
Help



The **User Manual** is viewable as a pdf document, with an active document map.

The **Cypher Instruments On Line** button menu item connects to the web site.

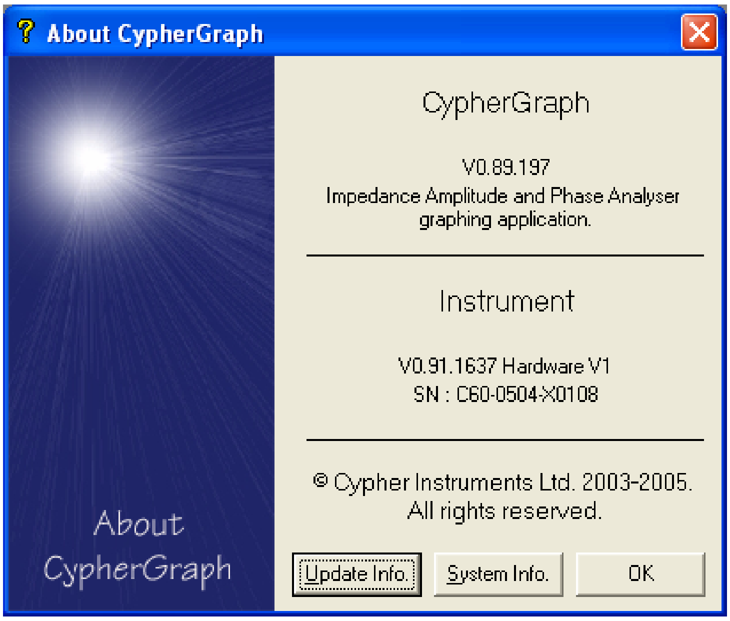
About Instrument lists the device properties of the connected unit. Other units will have different operating ranges and functionality.



The **About CypherGraph** menu item details the PC application and the embedded code version numbers and the hardware serial number.

The **System Info** button displays the system information summary of the host computer.

The **Update Info** button connects to the web site to check for the latest versions of the PC application and the instrument firmware. For more information see the section Software and Firmware Web Updates.



Tool Bars

CypherGraph has two tool bars for quick access to regularly used functions. The function of these is described below.

The horizontal tool bar

The horizontal **tool bar** contains several familiar and new tools. Some of these tools can be accessed by right clicking on the graph document and then selecting them from the drop down menu.

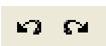
From left to right these are; **New** test, which prompts the user to choose an amplitude or impedance test; **Open** an existing file, again with a user choice of amplitude or impedance; **Save** a graph; **Export** a plot as a text file or a graph in an image format and **Print** the current graph on the installed printer.

From left to right these are; **Cut, Copy** and **Paste**. These allow the user to Cut or Copy a plot from one file and to Paste it into another. These files must have the same file extensions. Open two files. Click on the first graph and then select a pen number. This is the pen plot that will be copied. Press **Ctrl+C** to copy it. Now click on the second graph. Select a pen number that has not been used. Press **Ctrl+V** to paste the plot into second graph.

From left to right these are; **Graph view** options; **Add text** to the current graph; **Mark Data Points** on the selected graph; **Zoom extents**, which maximizes the graph display range; **Undo** and **Redo**, which step through the zoom history.

From left to right these are; **Start test**, which initiates the test procedure and graphing program (referred to as a plot); **Stop test**, which halts this process and **Repeat test**, which puts the unit into a repeat test mode. Note; we define a graph as being a collection of plots. There can be a maximum of ten plots per graph, each plot having its own pen colour and pen number. Graphs are stored as data files with the following file extensions; GAD for amplitude graphs and GZD for impedance graphs.

From left to right these are; **Test settings**, which causes the **Settings** dialog box to appear and Connect device, which selects the USB instrument and displays the unit serial number. These only function when a C60 is connected.



From left to right these are, **Previous document** and **Next document**, which allow the user to scroll through the open graph documents.

The **Help** tool provides on screen access to this manual.

The vertical tool bar

The vertical tool bar provides quick access to the features available on the Pen tab of the Graph View Options dialog box. This tool bar provides quick access for pen, colour, lock and view features. Pen selection 1 to 10 is also available through the number keys 1 to 9 and 0 for 10.

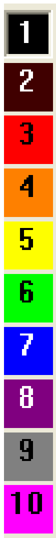
Lock pen locks the currently selected pen so that it cannot be over written.

Unlock All Pens that are locked on the graph in focus.

Display/hide the currently selected pen. This is **very** useful for identifying a single plot in a busy graph, particularly when monochrome is selected! Select a pen number and the press the eye button to hide/show the plot.

Display all pens on the graph in focus. Pens can be hidden by the Graph View Options selection. This retrieves them.

When a graph is open, left click on a pen box to Select the Pen number. The selected pen has then been chosen for the next pen function such as a plot or a copy & paste operation. Right click on a box to enter the colour definitions box. This controls the plot line colour of the graph document in focus.



Status bar

At the bottom of the application is the Status bar. This bar displays data about the graph in focus and the current test.

The Status bar displays 'Connected' when connected, Testing' when testing and 'Disconnected' when disconnected. In this mode, it also reveals the test progress.

The current pen number is shown. Click the pen bar boxes and this number will change.

The two frequencies A & B are displayed. These are changed when the (Settings – Apply) button is pressed or when (Sweep - X axis extents) values are applied or when Zoom Extents is asserted.

The Point counter shows the number of points in a test and is also used as a progress counter during a test. Change the number of test points using the slider in the Settings dialogue box and see them change in the Status bar.

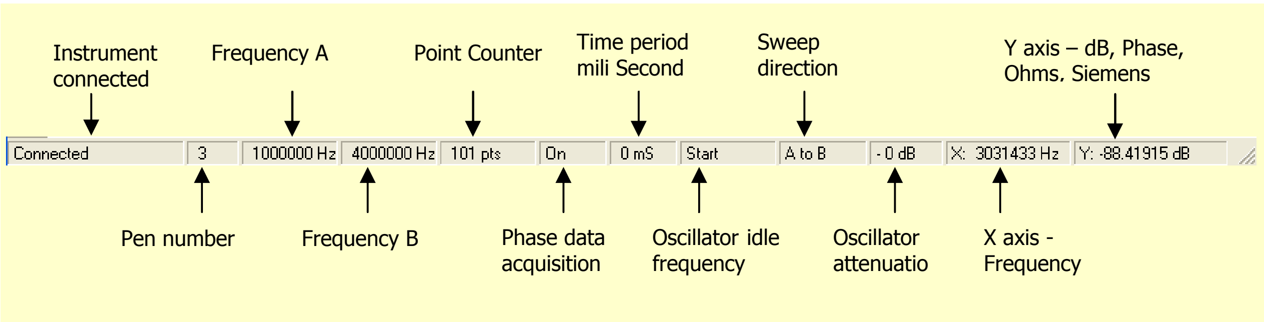
Next, the oscillator idle frequency is shown. In this example it was set to 1000Hz. Other displays include, Off & Start. These are all controlled in the Settings dialogue box.

The extra time period per test is displayed in milliseconds.

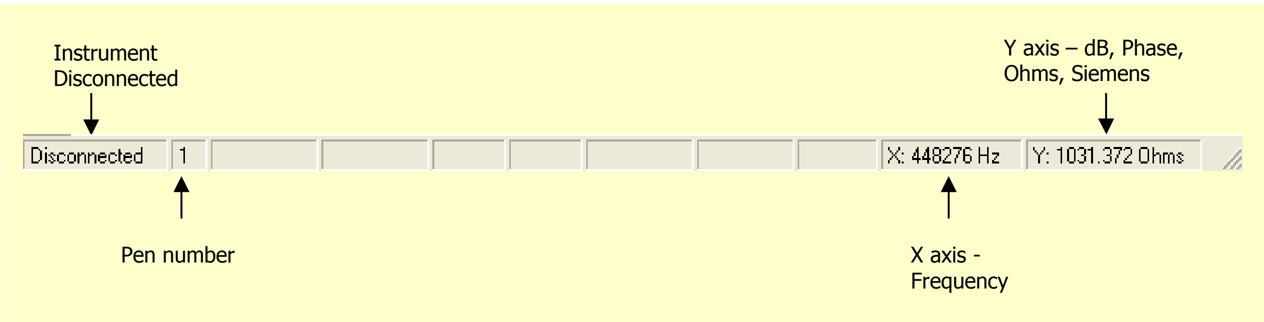
The sweep can be A to B, B to A or Alternate.

The oscillator attenuation is shown in dBs.

When a test point on a graph is selected (point & left click), the X & Y coordinates are displayed. The X axis is frequency. The Y axis can be gain/loss in dBs, phase in degrees and impedance/admittance in Ohms or

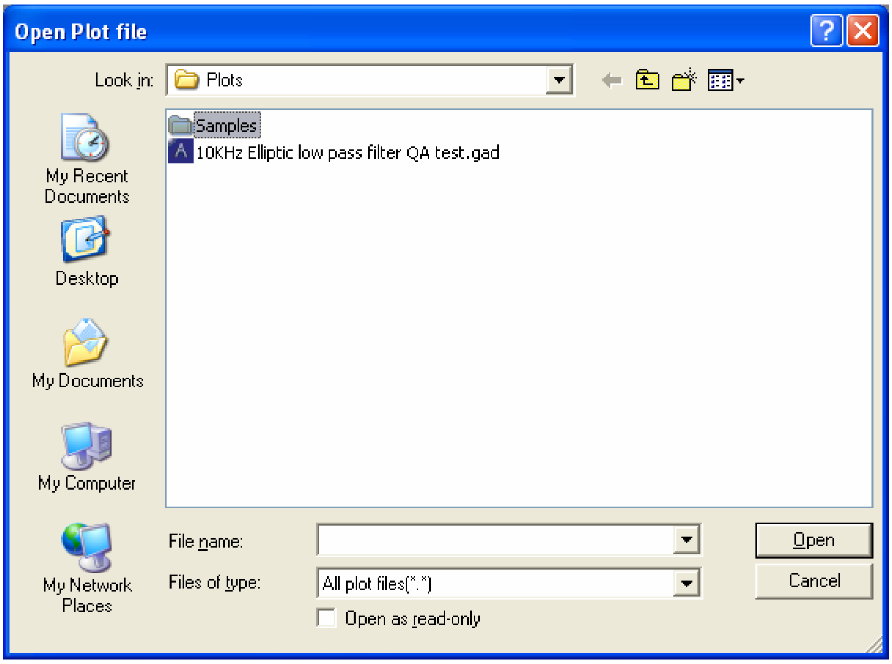


When an instrument is disconnected, the status bar can still be used to provide the XY coordinates of data points in a graph and to display the currently selected pen.

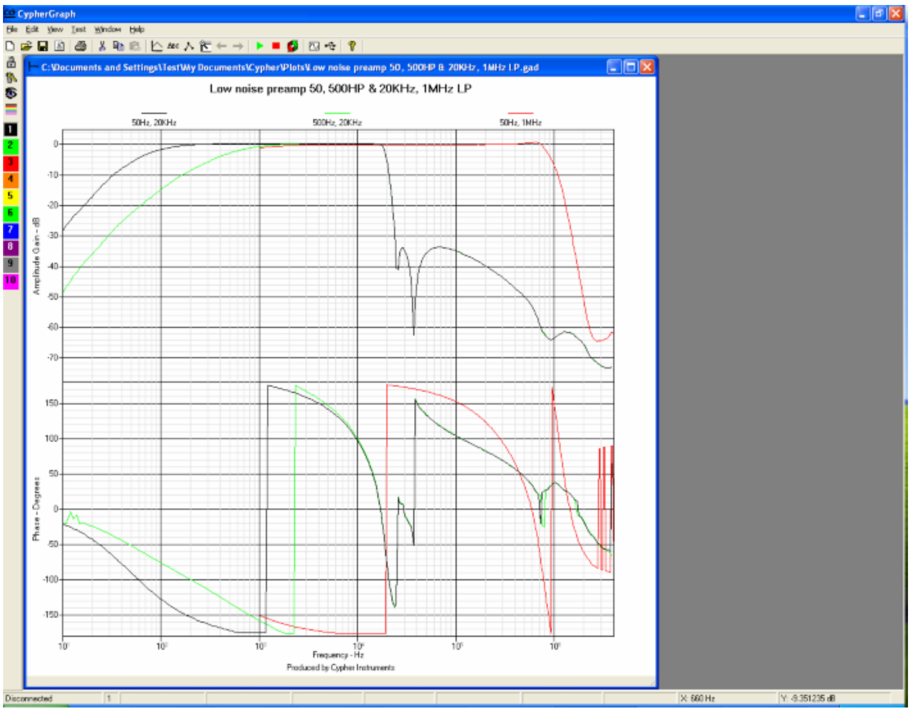


Viewing a graph

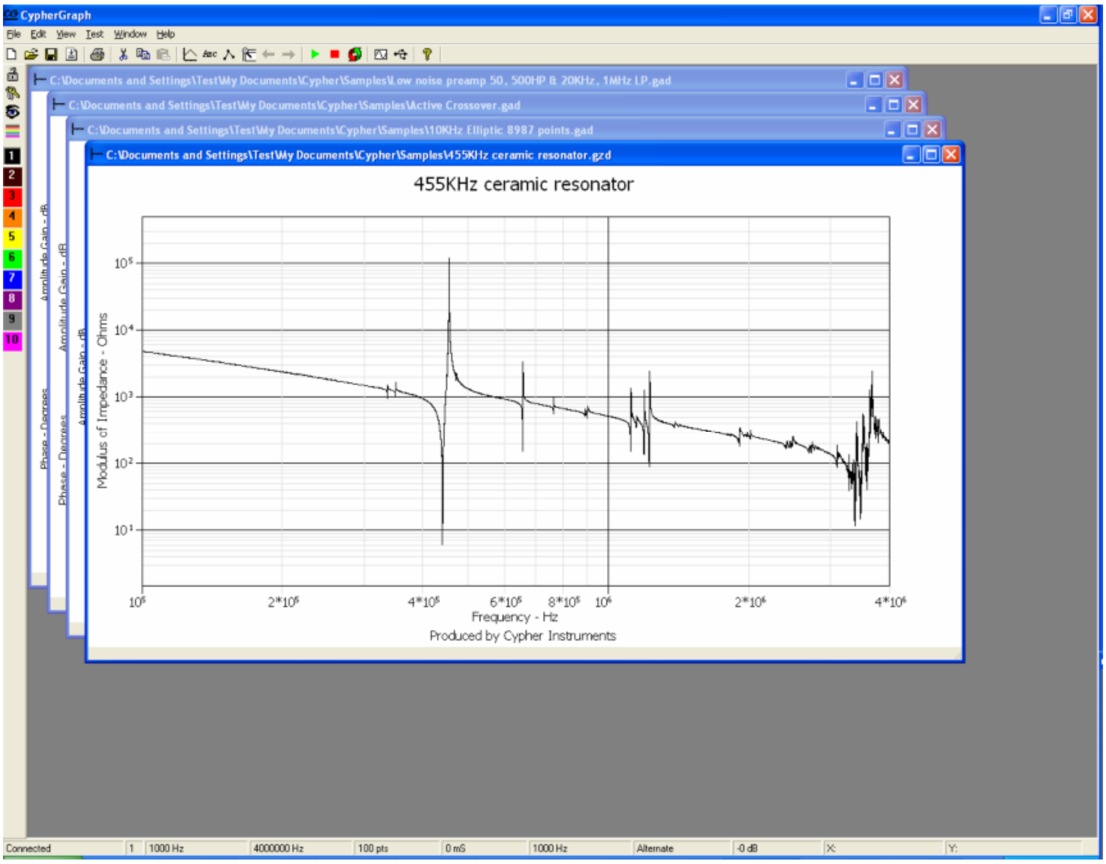
To view an existing graph, select **File Open** from the menu bar or press the **Open** file icon from the tool bar. A dialogue box will appear. Navigate to the Plots\Samples folder that contains the example plot files. Remember that there are two types of file, gad (amplitude graph) and gzd (impedance graph), which are identified graphically as an **A** or **|Z|** icon.



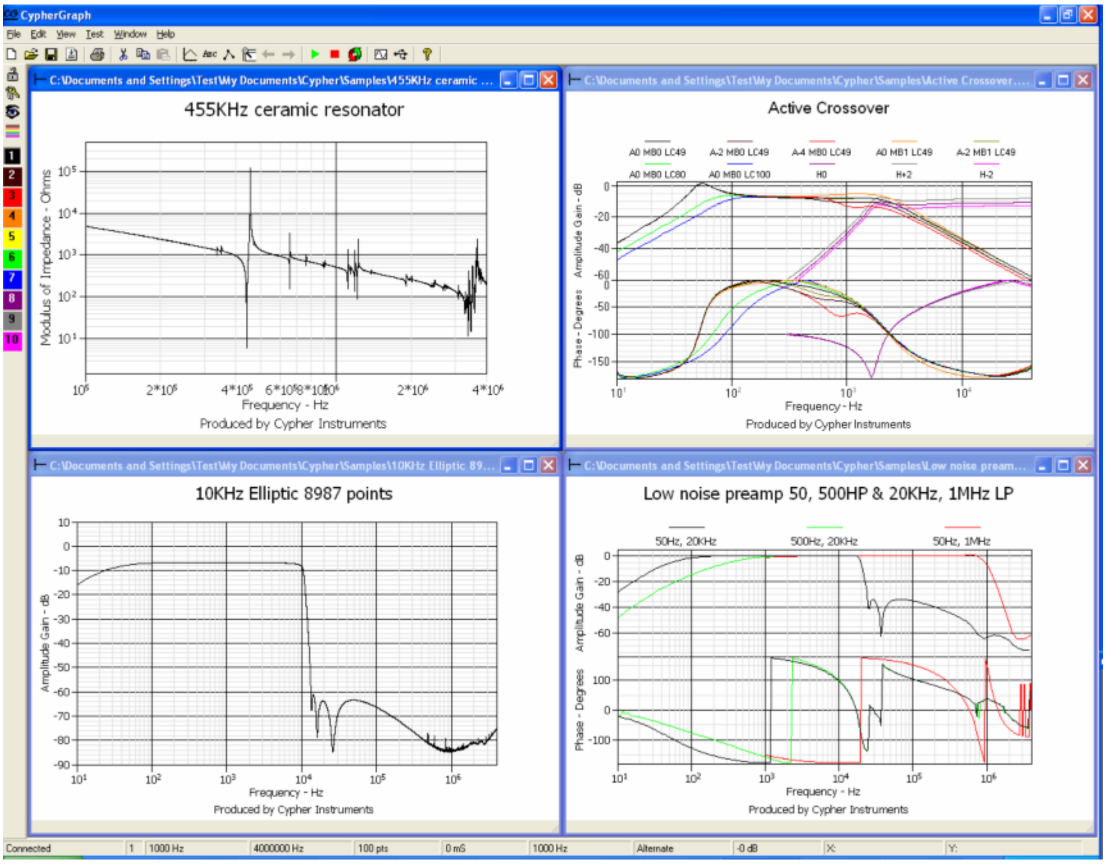
For illustration purposes, select the file shown below. This file contains the amplitude and phase response data values for a low pass filter which is then displayed as a graph.

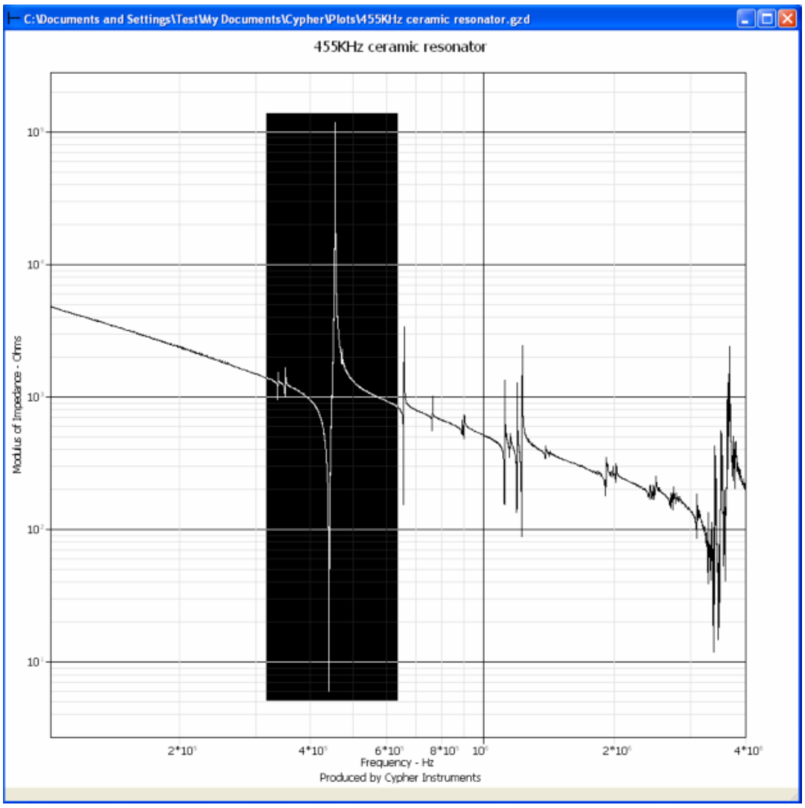


Load up three other files, including the '455KHz resonator' response. These are displayed as a multi document cascade. In the **Open Plot** file dialog the **Ctrl** key can be held down to select **multiple** files.

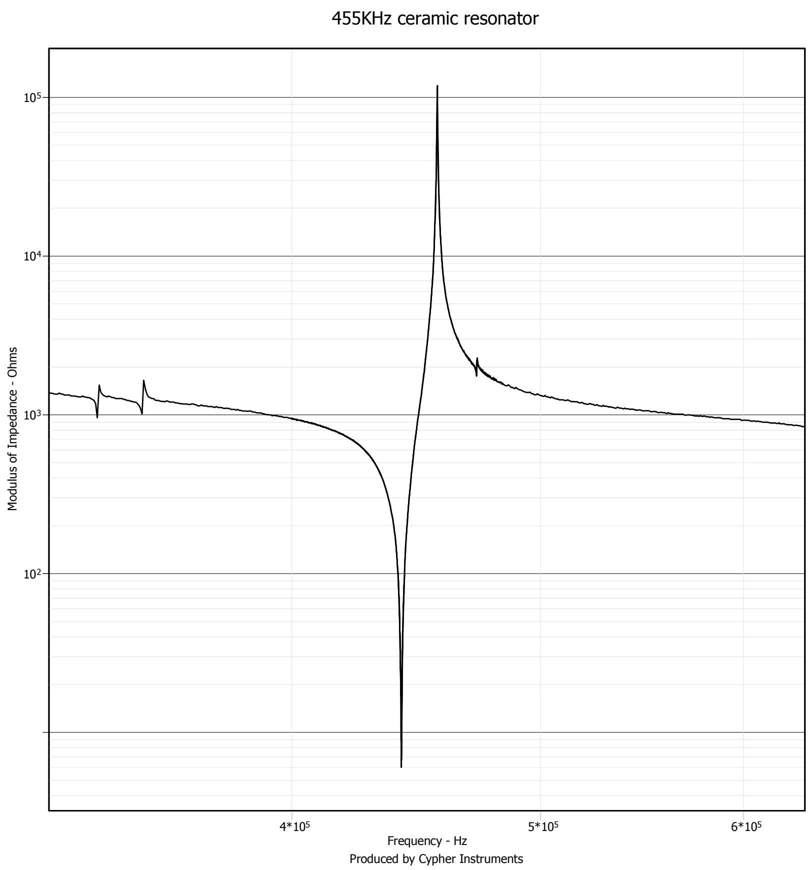


Select **Window Tile Horizontal** from the menu bar. The four graphs will appear in a two by two matrix. Click on any of the graphs to change the graph document in *focus*.

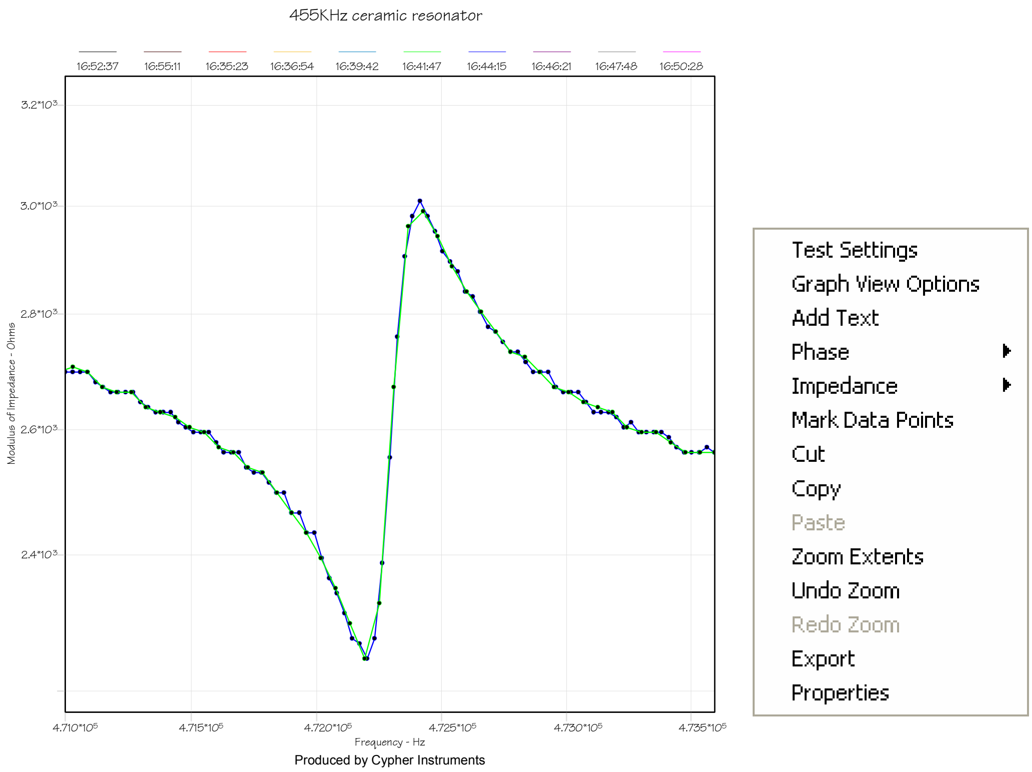




There are some interesting impedance resonances in this electro acoustic device. Using the mouse, left click on the graph and then draw out a rectangle (shown as a negative image). When the left click is removed, the graph will **Zoom** into the rectangle.

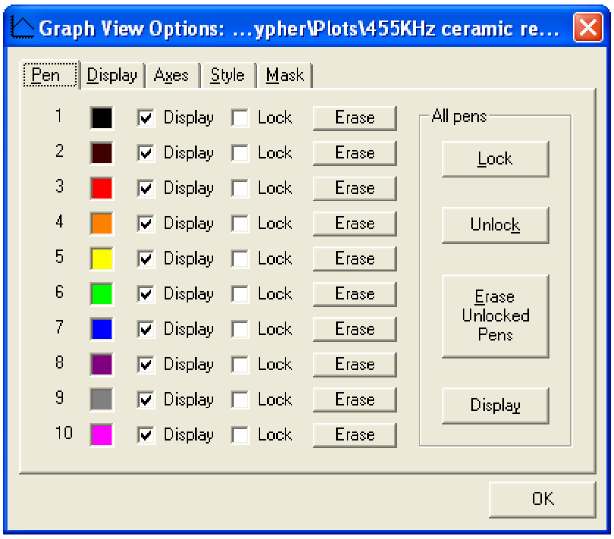


The zooming can be repeated almost endlessly, eventually revealing the noise floor, assorted errors, interference and the quantization steps of the system.



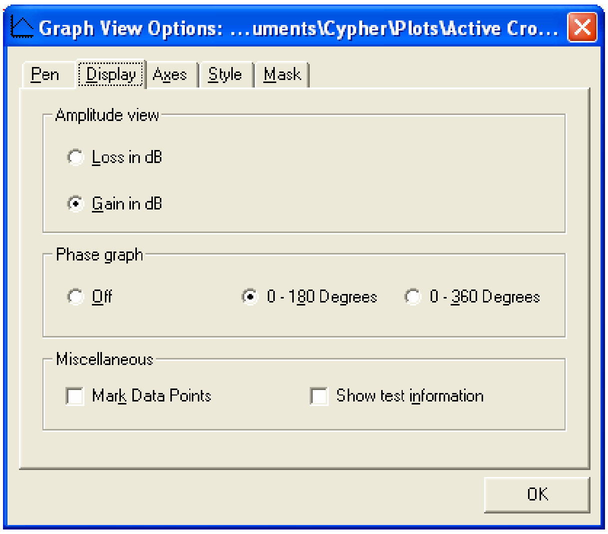
Right click on the graph and a menu box will appear. This provides a fast route to the graphing controls. **Undo Zoom** will now step back through the different areas of the graph you have zoomed into. **Redo Zoom** steps forward once you have done an Undo Zoom.

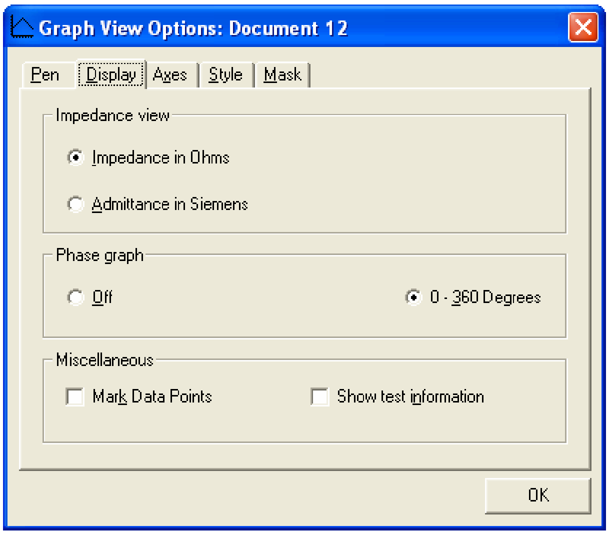
The Graph View Options



The Graph view options dialogue box allows the user to exercise control over the 10 pen plots that make up a graph. Right click on a graph to invoke the Graph View Options box. The Pen tab allows pen colours to be set. Double click on the coloured box to activate a colour palette, and then select a pen colour. Each graph can have a different set of pen colours, which can be set before performing a test and can be changed afterwards. Each Pen plot can be displayed or hidden, which is useful when there are many pen plots on a graph. Pens plots can be locked, so that they cannot be over written. In this way, a set of locked plots can be displayed as a reference. Pen plots can also be erased

The Display tab sets the Amplitude View (left) to be Gain or Loss represented in dBs. The Gain display range is from +10dB to -90dB and the Loss range is from -10dB to +90dB. These two views are inverted images of each other. Also, Impedance view (right box) selects either Impedance in Ohms or Admittance in Siemens.

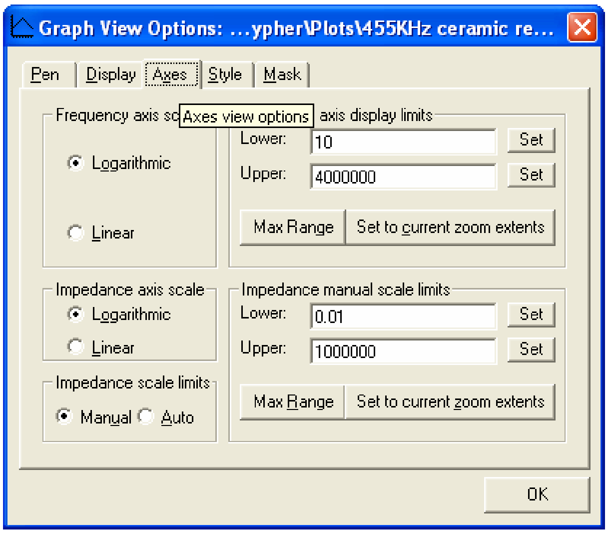


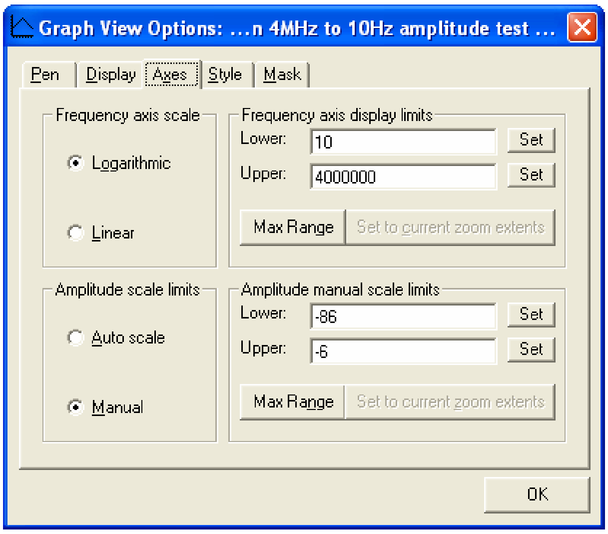


The Phase graph controls the phase display range. When active, the phase graph can display a 0º to 180º range or a ±180º range. The phase electronics uses a sign detector to un-wrap the phase graph and to double the display range. This works well on big clean signals and not so well on very small signals with poor S/N ratios. If the input signal has a poor S/N ratio or has interference, then the results will be degraded.

The 'Mark Data Points' check box, toggles the data points on and off. The Show test information box reveals the software version number and the graph date.

The Axes tab sets the frequency axis to be either logarithmic or linear. Most frequency responses are best displayed as dBs versus log frequency. In this way, many filter and impedance responses have 'straight line' slopes. However, time delay networks, such as comb filters, have peaks and notches which are linearly spaced and so a linear axis works well for this type of system. The Upper and Lower viewing frequencies can also be set. Also the amplitude display range can also be set (left box) or the Impedance range (right box).



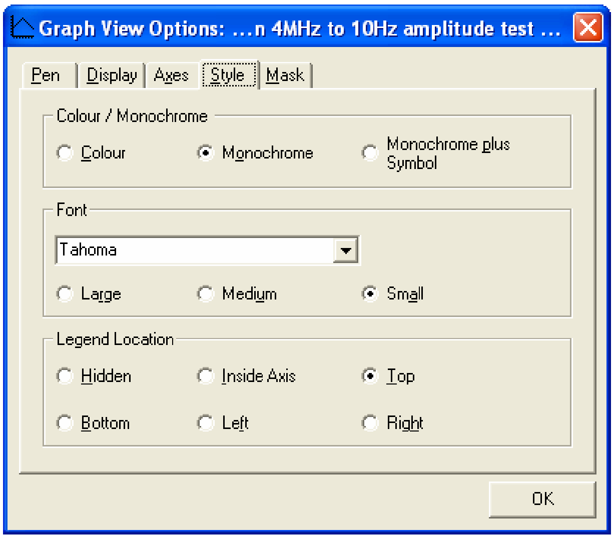


The Style tab controls the appearance of the graph.

The graph can be plotted in colour, monochrome and monochrome with symbol markers. Some technical magazines still publish in black and white.

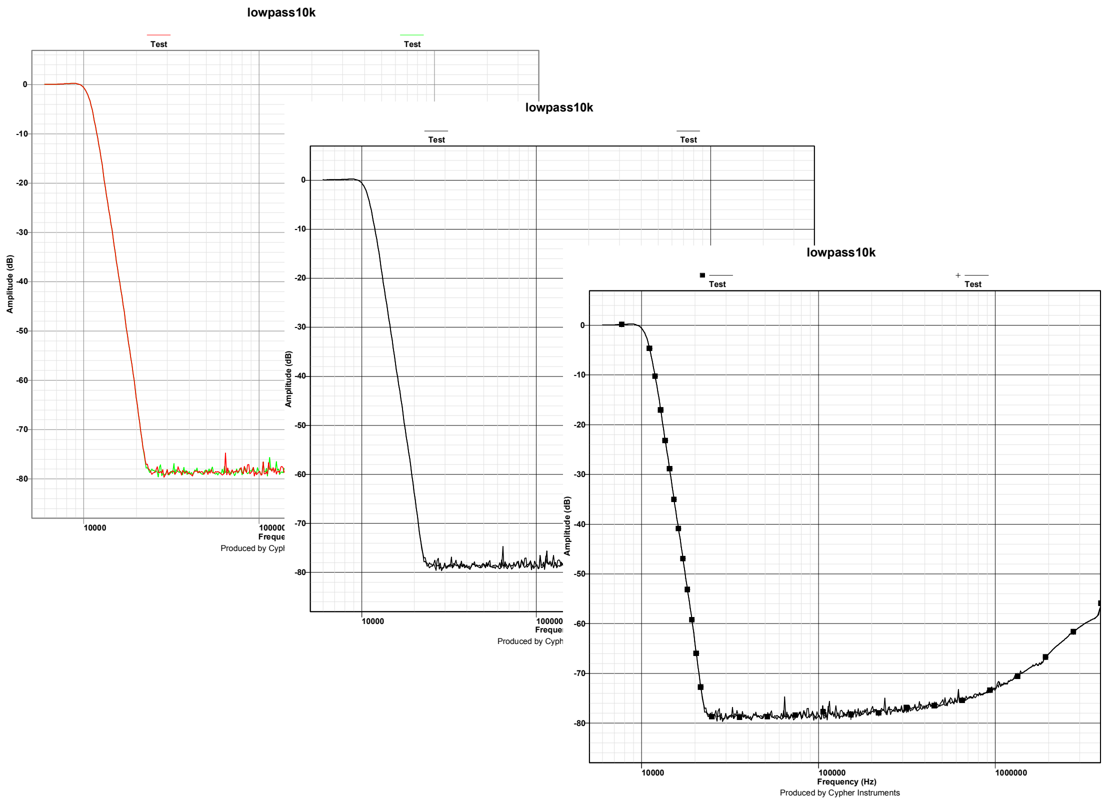
The font used inside the graph can be selected from the PC font folder. This allows the user to match the graph font to a font used in a document. Three sizes are available. These sizes impact on the available area in which to plot the graph.

The large font is useful for the wmf file formas. The font appears to be very large on the screen, but is suitably large in a document. The wmf process for text in resizable graphs is not *wysiwyg*.

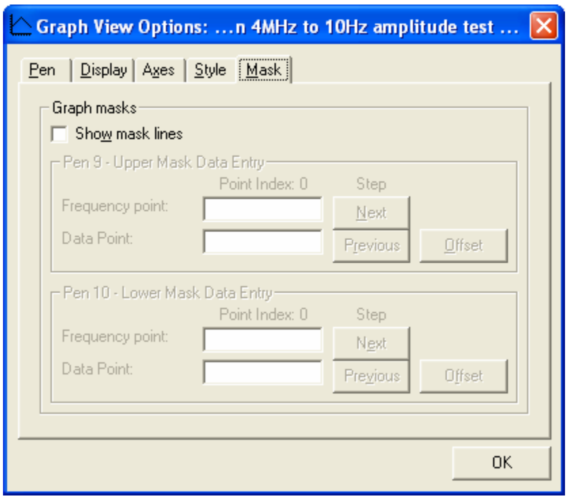


The graph Legend Location can also be controlled by the user. These give the user even more choices over the visual look of the graph. The examples below use the 'Top' option.

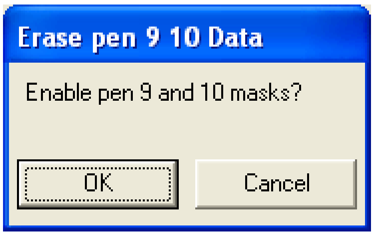
Below are colour, monochrome and monochrome plus symbol views of the same graph

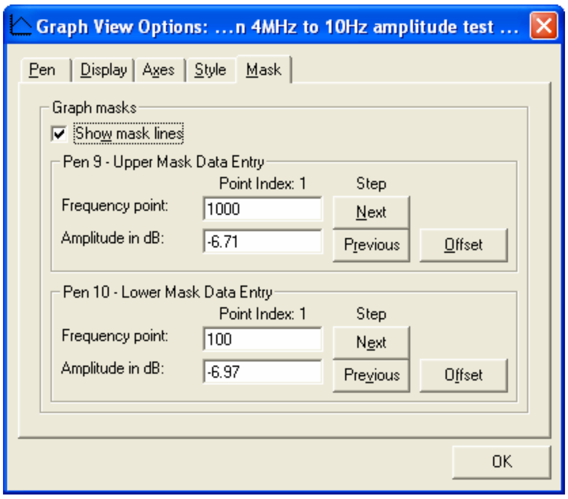


The Mask tab enables lines to be drawn on a graph. These lines can be used as boundary markers to test device performance. A set of upper and lower boundary lines forms a test mask, through which the response of the DUT has to travel. Pass or fail can be visually determined by the user, or a Check mask test can be applied. These masks can be applied to amplitude responses and impedance responses.



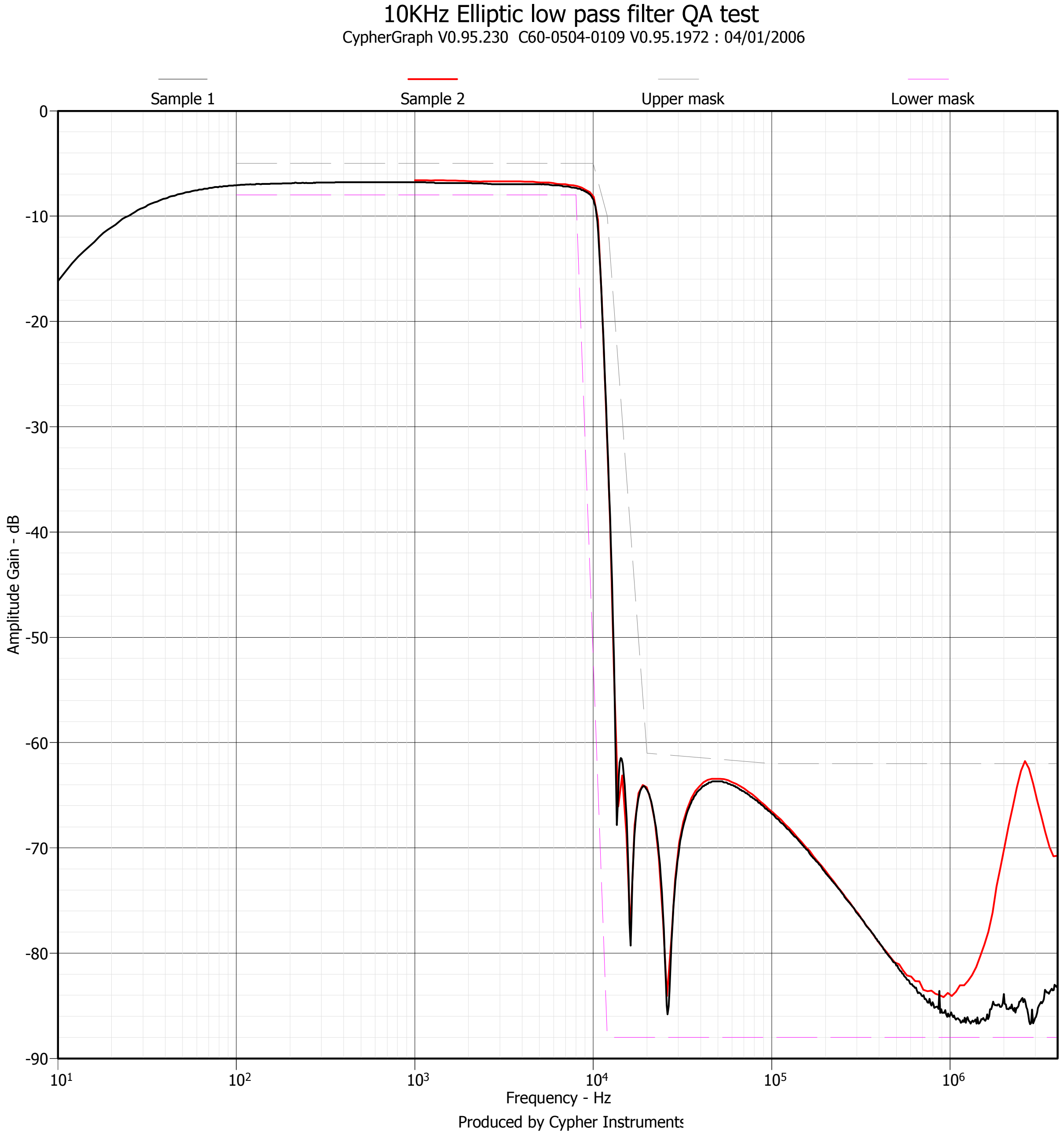
The upper and lower masks consume two of the ten available pens. These masks have been assigned to pens #9 and #10. Select the Mask tab and click on the 'Show mask lines' box. A small dialog box reminds the operator that any existing plots that used pens #9 and #10 will be erased! For a new graph, this warning has no meaning. For an existing graph, you could end up erasing plots.





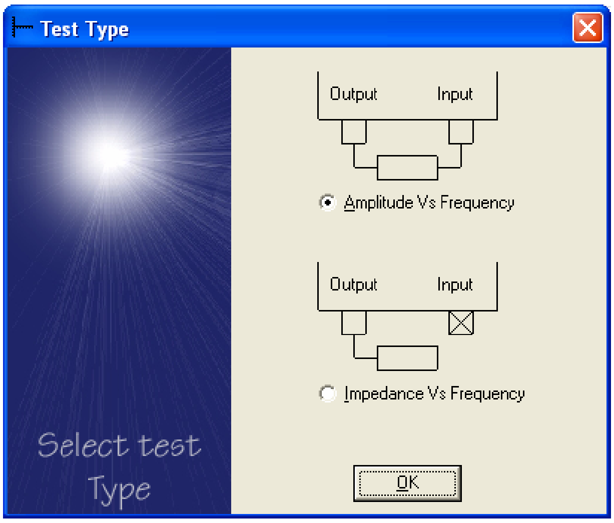
In this example, an elliptic low pass filter response will have a mask drawn around it. Data points are entered manually into the Frequency and Amplitude boxes for both the upper and lower Masks. A mask is constructed from 2 to 24 points. As the data points are entered, they appear on the graph as dotted lines. The Next and Previous buttons allow the user to change data points. The two masks are treated the same as any other plot line.

An offset button allows masks to be shifted up and down.



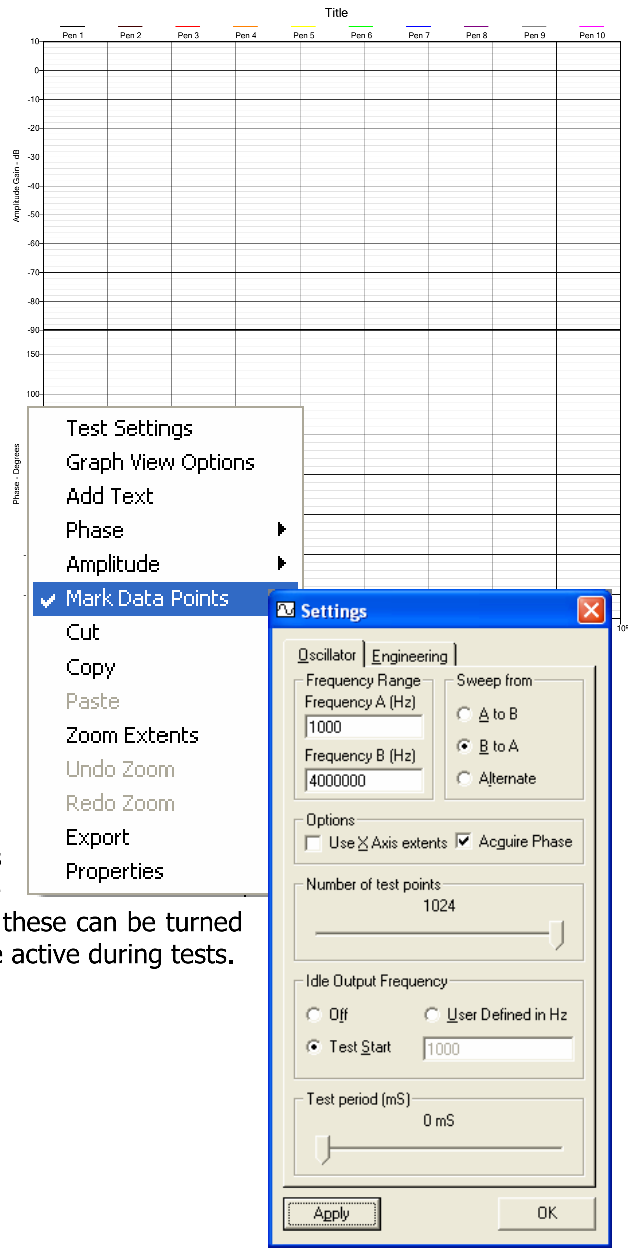
Note: When a mask is enabled, the logarithmic/linear axis view options are frozen in their current state. This removes ambiguities that may result from subsequent changes to the axis view settings.

Measuring Amplitude Response



To create a new graph, connect the C60 to the PC using the USB lead. Connect the Device Under Test (DUT) from the output BNC, into the input BNC. In the following examples a passive low pass Elliptic filter is used. This filter has a fast roll off slope and some very interesting notches in its response. The following illustration will apply equally to any filter that is used. If there is no device connected, press **F6**. The connection status can be seen on the Status bar.

Select **new file** from the menu bar or press the new file icon from the tool bar. A dialogue box will appear with a choice of two modes of operation; Amplitude response or Impedance measurement. Select Amplitude Vs Frequency and click OK.



A blank graph sheet will appear with a maximum range of amplitude, phase and frequency values. All plots are drawn inside this sheet. Tests can be performed inside the area of the sheet, by limiting the frequency limits, zooming and by turning off the phase portion of the display.

Right click on the graph area and a context sensitive menu will appear. Select Test Settings to get the Settings dialogue box. Set the A B frequency range and click the Apply button or press return. In this test, a frequency range of 1kHz to 4MHz was selected. Do not check the Use X axis extents box as this over rides the Frequency boxes (*it greys them out*). The sweep direction is B to A.

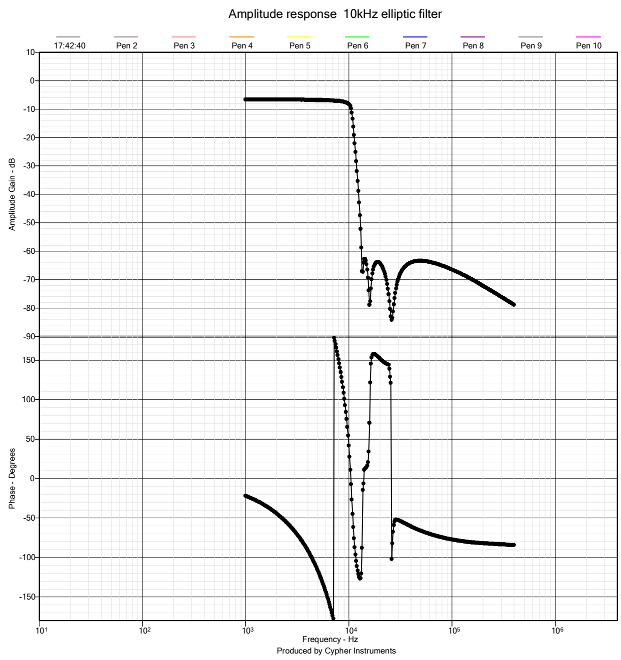
Set the number of test points using the slider. This is active even during a test.

Set the Idle Output Frequency. The choices are Off, User Defined in Hz and the Test Start frequency.

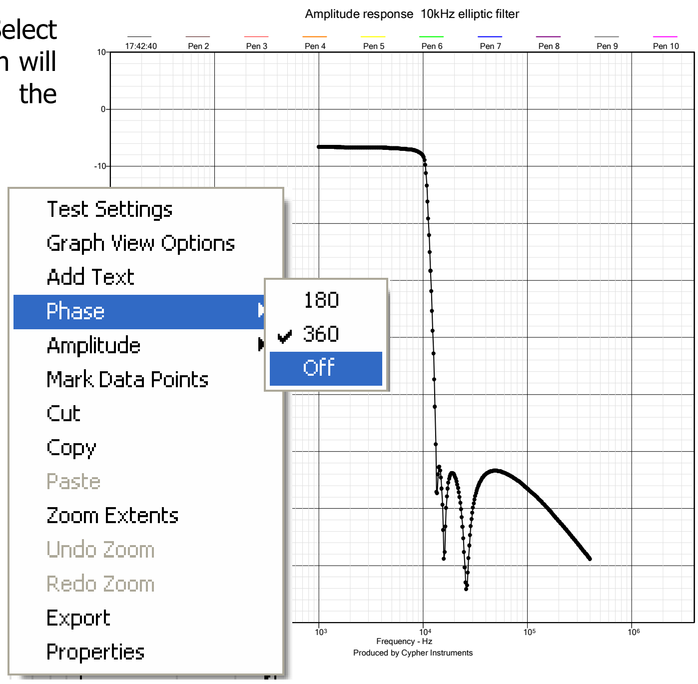
An additional wait period can be introduced by setting the Test period slider.

The test can now proceed. Click on the Start Test tool (green arrow). A sine wave sweep of the DUT produces Amplitude and Phase readings that are displayed on the graph. In this example the data points are Marked, but these can be turned on and off during a test. Also, Zoom and Undo Zoom are active during tests.

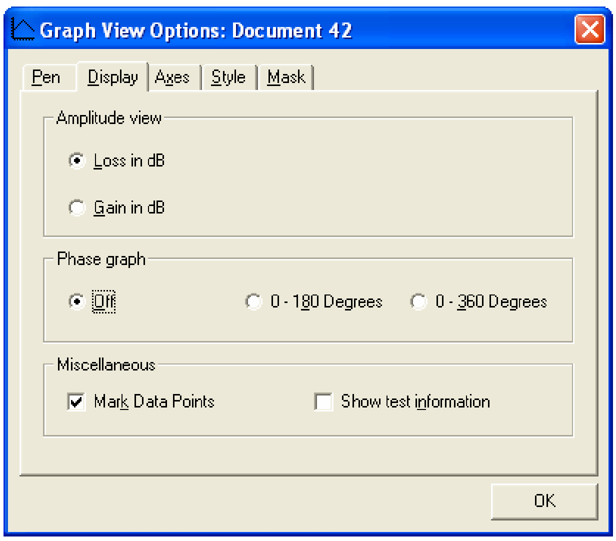
The Amplitude response graph reveals the rapid roll off slope of an eighth order low pass elliptic filter. This filter has four notches in the stop band, three of which are visible. The amplitude response starts at -7dB and falls into notches going down to -84dB. The phase response is dramatic. An eighth order low pass filter has lots of phase shift caused by the 8 poles. Also, each time the response passes through a notch, the phase response does an abrupt 180o reversal. This happens at zero amplitude which makes measurement rather difficult. However, the graph shows the phase response even at a notch, with display wrap around at ±180o. When the signal level is very small, the phase detector is not being driven by a sine wave, but by noise. In this circumstance, the detector mechanism decides that the phase is ±90o. As a rule of thumb, if the phase is ±90o, then the input signal has disappeared!



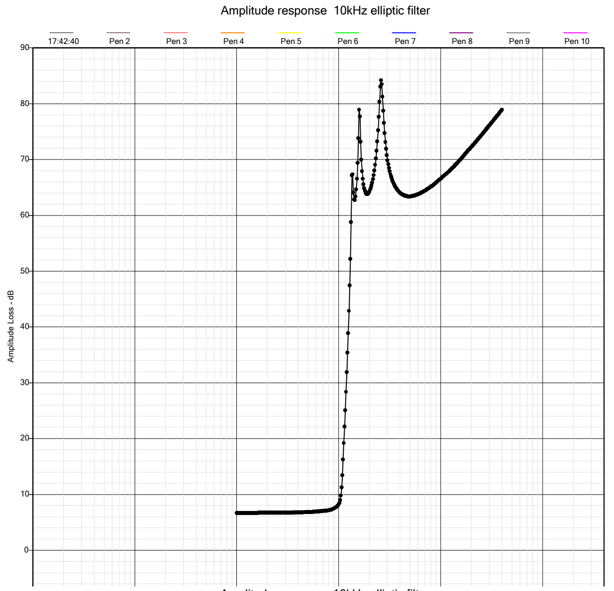
Right click on the graph. A menu will appear. Select Phase, then Off. The phase portion of the graph will vanish, which doubles the display size of the amplitude gain plot.



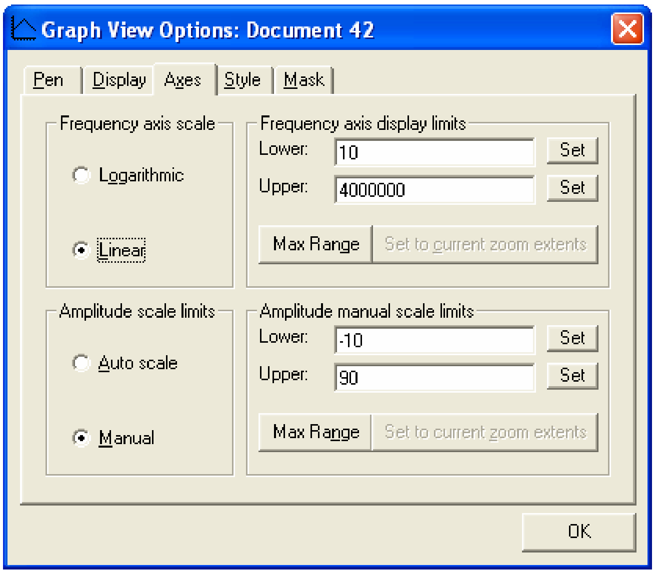
Again, right click on the graph and select Graph View Options, Display tab. The Amplitude view can be shown as Gain or Loss. Click the Loss dial.

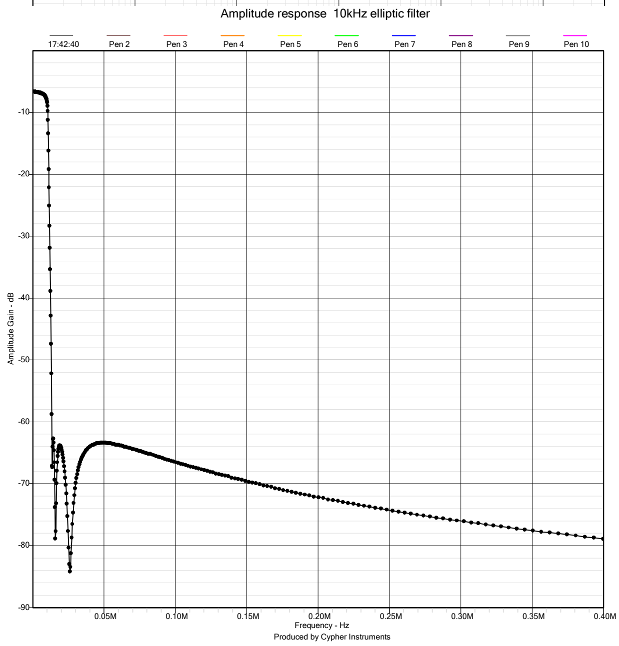


Now the graph shows Loss and not Gain. The graph has just been inverted. It used to be the fashion to display frequency responses this way up in Germany and Japan. For all we know, it still is!

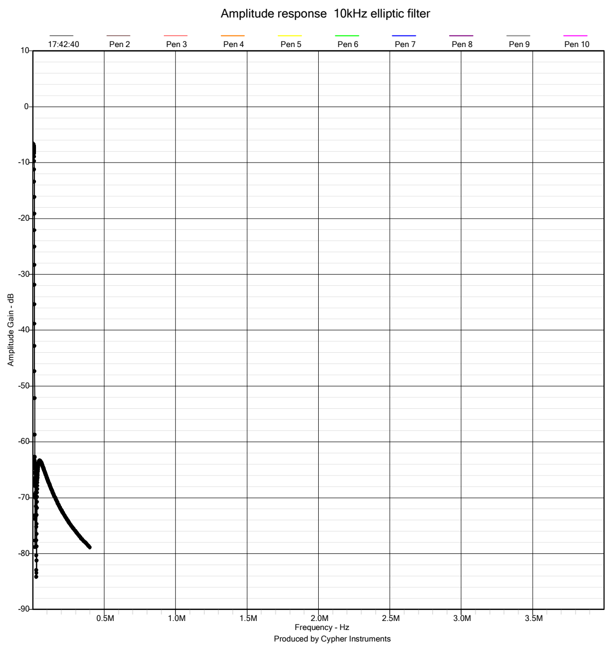


Use Graph View Options to return to a Gain display and then select the Axes tab. Select the Linear Frequency axis scale.





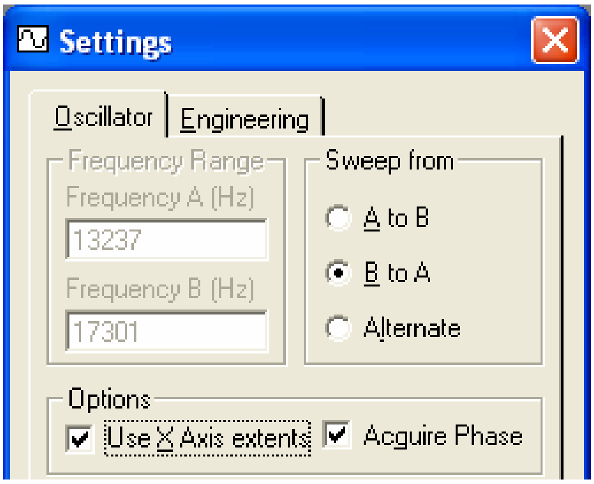
Now the graph is plotted on a linear frequency axis from 10Hz to 4MHz. The 400KHz response only occupies 10% of the graph paper. If the response had been a 4KHz plot, then it would have only used 0.1% of the linear graph range. This is 1.5 pixels on a PC display! The graph would still exist, but on a linear axis it would not be visible.



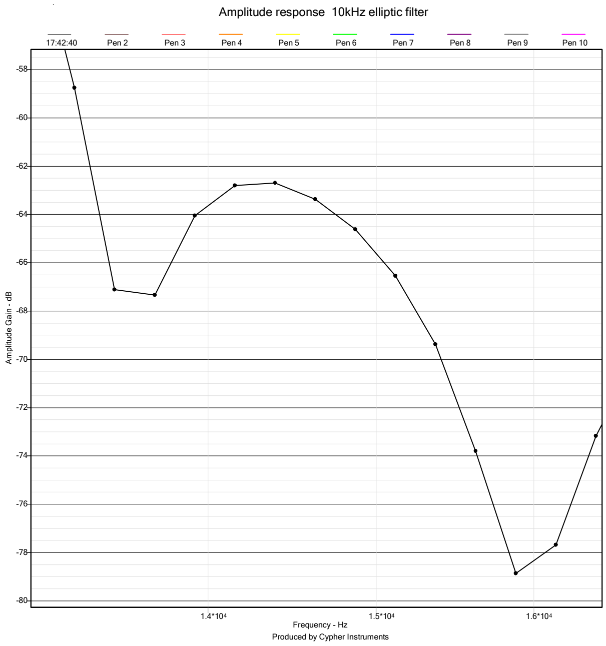
Point the cursor on the graph and drag a box around the area of interest. The graph will be redrawn to reveal the selected area. Generally, Gain versus Logarithmic frequency is the best way to display test results. Many natural systems have responses that are proportional to frequency which result in straight line plots on a log/log graph.

However, time delay responses such as comb filters are best displayed on a linear frequency axis.

Return the view to a logarithmic frequency axis. On the Settings dialogue box, click the Use X Axis extents box. This allows the user to zoom into an area of interest and to retest it. When this is happening, Frequency A & B are greyed out.



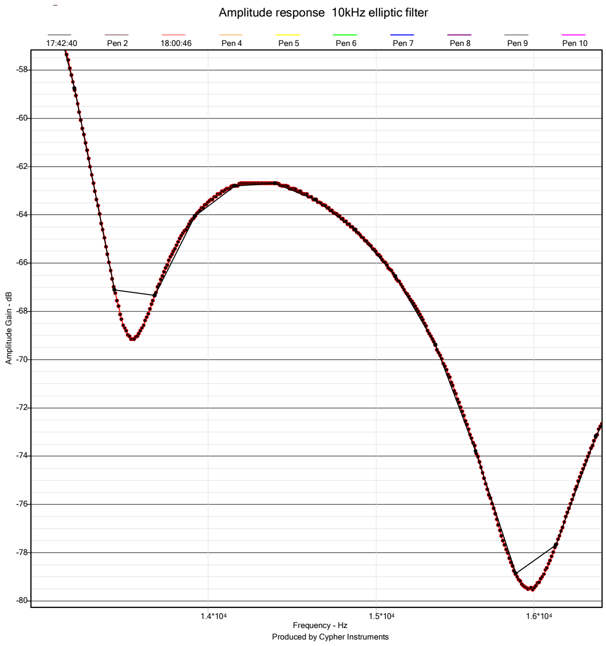
The first two notches of the filter are quite interesting. Click and drag a box around them. However, when the graph zooms in, they don't seem that good. They don't have enough data sample points to reveal the response of the filter. Remember, lots of dots make good graphs, but you are only allowed 1024 dots per plot. Also, lots of dots takes lots of time.



The red pen was selected (by clicking on it) and a new test performed (click on the green Tool Bar arrow). The new test uses the X axis extents of the zoom window, but the same number of test points as before. The notches are tested with much finer frequency resolution. Note that although the black plot suffers from poor resolution due to under sampling, its data points fall on the much finer plot of the red pen. This means that all the data points are correct, irrespective of resolution.

Plots are limited to 1024 data points each. It is possible to make a plot with 10240 data points. Break up the frequency axis into 10 sections. Use a different pen for each section and set all the pen colours to be the same. Note; 10,240 test points will take a while.

Don't forget to save your graph, or it will be lost forever.



Obtaining optimum results

The input of the C60 is sensitive. It has a 1M ohm input impedance (at low frequencies) and a small signal bandwidth of more than 10 MHz. A 2V peak to peak sine wave presented to the input is equivalent to 0dB on the graph. Other signal level relationships are show below.

2Vpp	=	0dB
200mVpp	=	-20dB
20mVpp	=	-40dB
2mVpp	=	-60dB
200µVpp	=	-80dB
100µVpp	=	-86dB

A 100µVpp sine wave is a very small signal. This is the smallest signal that the C60 can measure from a low impedance source before the noise floor becomes dominant. Any unwanted signals that enter the input will be misinterpreted by the unit. For example, mains hum, power supply switcher noise, radio interference, magnetic fields, electrical and acoustic noise will all be faithfully interpreted as amplitude, phase and impedance readings and plotted as such. The C60 is not capable of recognizing good signals from bad ones. The user has to be careful to perform tests in a 'quiet' environment.

Some PCs have electrically noisy power supplies. If the C60 is powered from such a PC and it is used to test another switcher-powered unit, then large switching currents can flow through the system. This can introduce interfering spikes into the test signal which produce spurious results. Best results are obtained by using an electrically floating, battery powered laptop PC. Even connecting a digital scope to the test scenario, can inject digital interference into the readings.

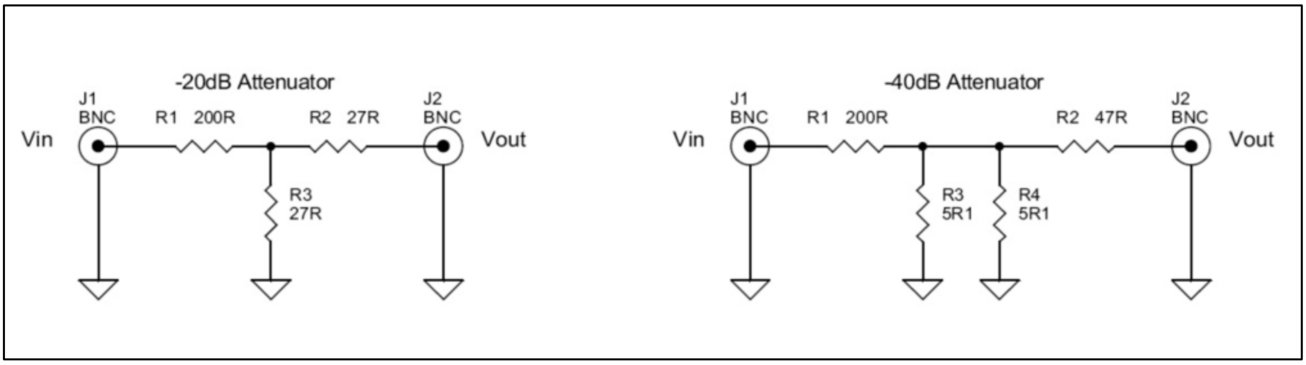
Also, using USB hubs can introduce extra power supply noise into the test system. Other units connected to the hub will add their own 'noise' currents into the ground wiring. For best results use a single USB connection from the C60 to the PC that is controlling it.

Unscreened DUTs can pick up electric, magnetic and electro magnetic interference. To avoid this, the C60 and the DUT should be placed inside a metal box. Connect the box to the C60 'ground', and this will provide a quiet environment to perform tests. Aluminium will stop mobile phone radio emissions from interfering with the tests, but it will not stop magnetic fields emanating from electromagnetic devices. Steel (not stainless) will attenuate magnetic fields. Sometimes, just a good ground plane under the C60 is sufficient. A sheet of copper or aluminium connected to local mains earth via a big flat conductor, or the ground of the C60, will provide a target for electric fields to collapse into and yet allow easy access for the operator.

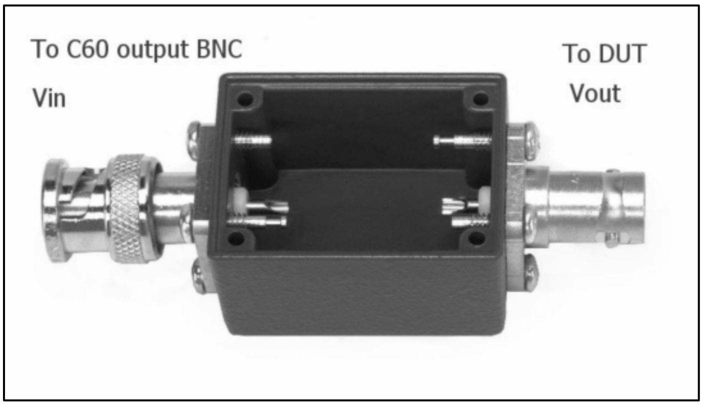
Avoid big wire loops connected to the DUT. They look like inductors in the impedance test mode and act as radio antennas which both transmit and receive.

Noise and vibration can introduce error signals into a C60 test. Everything seems to be micro phonic. Ceramic capacitors are actually used as acoustic transducers, although they polarize them during manufacture to increase their sensitivity. Coaxial cables are micro phonic. They make noise when they are flexed, due to the tribo electric phenomena. They are used as a linear microphone to monitor road traffic usage.

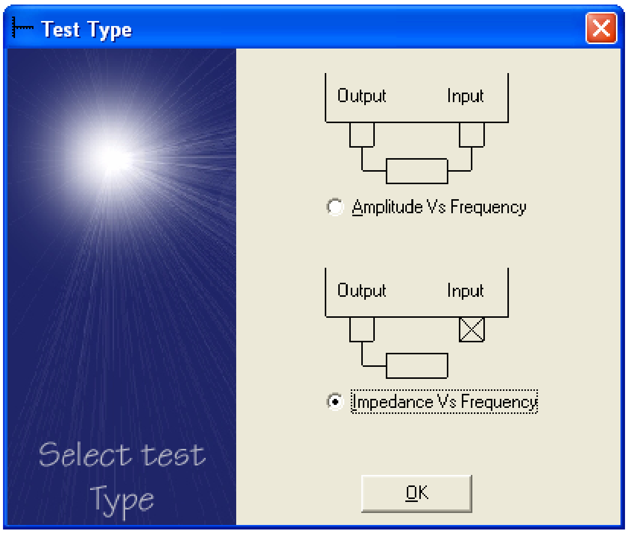
The C60 has an output attenuator with a 20dB range, available in 2.5dB steps. The output voltage can be varied from 2Vpp to 200mVpp, although best results are obtained when the C60 is running at maximum voltage. This might not be suitable for many amplitude test scenarios. For example a microphone amplifier input may overload unless the input is very small. The solution to this problem is to use an external low impedance attenuator.



The circuit shows a 20dB and a 40dB resistive attenuator. Use 1% wire ended metal film resistors, as these are relatively non reactive. The attenuation is about 1% accurate and the output impedance is approximately 50 ohms. Solder the components into a metal BNC adaptor box. Connect both BNC grounds together with thick tinned copper wire. A signal level from 0dB to -60dB can be generated by introducing of one of these attenuator boxes into the signal path, and by controlling the C60's attenuator.



Measuring Impedance Response

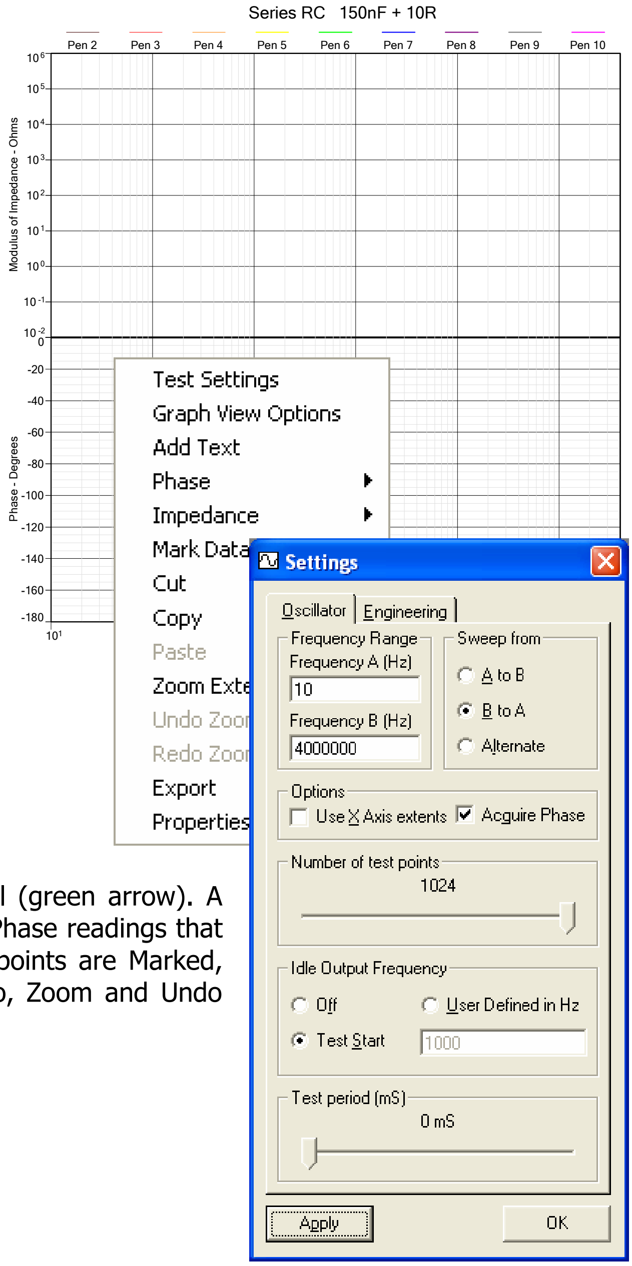


To create a new graph, connect the C60 to the PC using the USB lead. Connect the Device Under Test (DUT) to the output BNC. The input BNC is not used for impedance tests. In the first example a 150nF capacitor in series with 10R is used as the DUT. If there is no device connected press **F6**. The connection status can be seen on the Status bar.

Select new file from the task bar or press the new file icon from the tool bar. A dialogue box will appear with a choice of two modes of operation; Amplitude response or Impedance measurement. Select Impedance Vs Frequency and click OK.

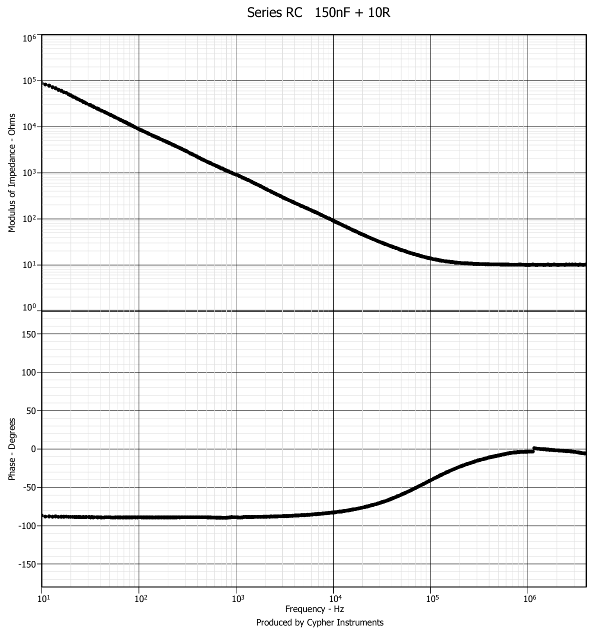
A blank graph sheet will appear with a maximum range of impedance, phase and frequency values. All plots are drawn inside this sheet. Tests can be performed inside the area of the sheet, by limiting the frequency limits, zooming and by turning off the phase portion of the display.

Right click on the graph area and a context sensitive menu will appear. Select Test Settings to get the Settings dialogue box. Set the A B frequency range and click the Apply button or press return. In this test, a frequency range of 10Hz to 4000kHz was selected. Do not check the Use X axis extents box as this overrides the Frequency boxes (*it greys them out*). Set the number of test points using the slider.



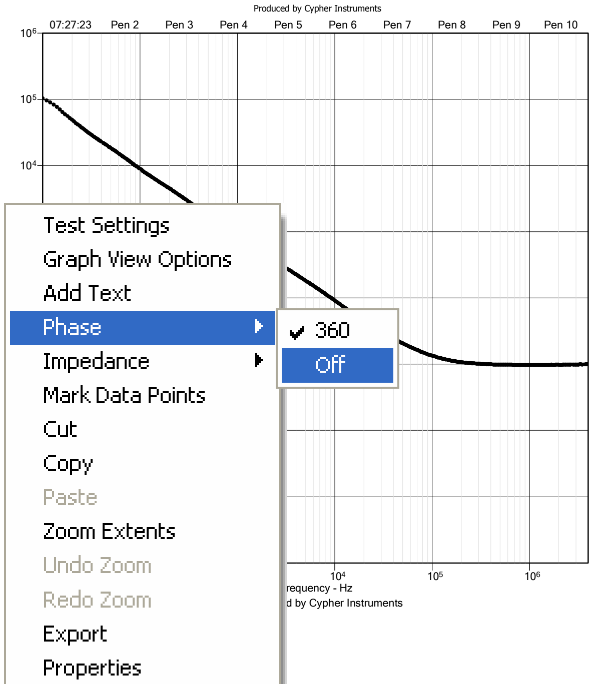
The test can now proceed. Click on the Start Test tool (green arrow). A sine wave sweep of the DUT produces Impedance and Phase readings that are displayed on the graph. In this example the data points are Marked, but these can be turned on and off during a test. Also, Zoom and Undo Zoom are active during tests.

The Impedance response graph reveals the slow roll off slope of capacitor in series with a resistor. The impedance of a capacitor will fall by half for every doubling of the drive frequency, until it equals the resistor value. On a log/log graph this is a straight line with a slope of -6dBZ/octave or -20dBZ/decade. That is, one decade cycle of Impedance for every decade cycle of Frequency on the graph. The Z plot goes flat at about 10 ohms. The plot then has a relatively constant slope, which is typical for a simple reactive device. Also, testing down to 10Hz takes a long time!

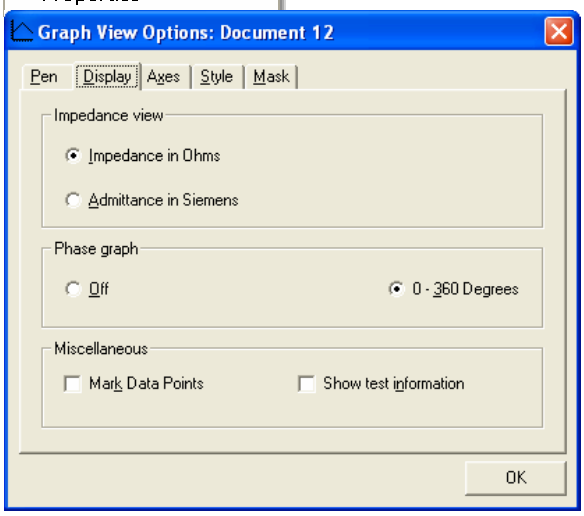


The phase plot shows the phase shift of the current flowing through the DUT relative to the voltage across the DUT. When the capacitor behaves like a capacitor, the phase shift is -90º. The graph displays the magnitude of the impedance and the phase shift as a function of frequency. The graph represents the complex impedance of the DUT.

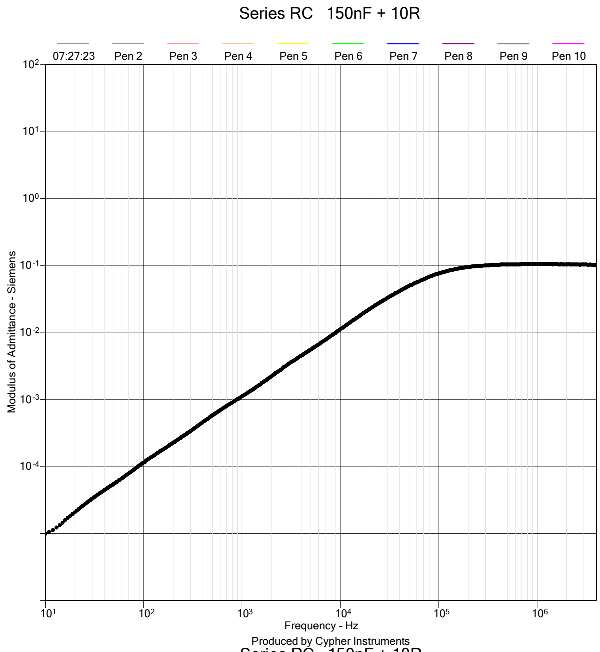
Right click on the graph. A menu will appear. Select Phase, then Off. The phase portion of the graph will vanish, which doubles the display size of the Impedance plot.



Again, right click on the graph and select Graph View Options, Display tab. The Impedance view can be displayed as Admittance, which is measured in Siemens. Click the Admittance dial.



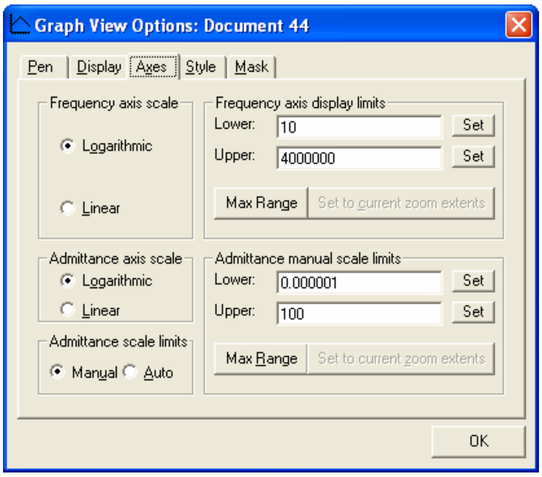
Now the graph shows Admittance and not Impedance. The graph has just been inverted and the vertical units changed.

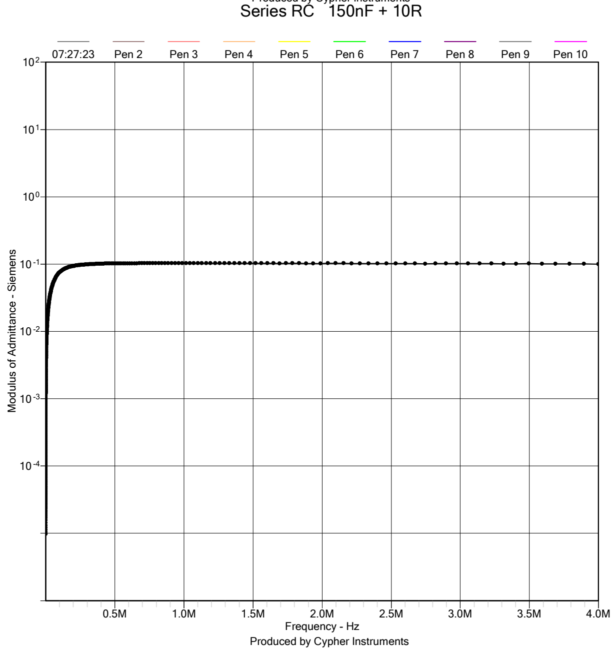


Conversion of Impedance to Admittance

1 mOhm	1 KMho	1 KS
1 Ohm	1 Mho	1 S
1 KOhm	1 mMho	1 mS
1 MOhm	1 uMho	1 uS

Use Graph View Options to select the Axes tab, then select the Linear Frequency axis scale.

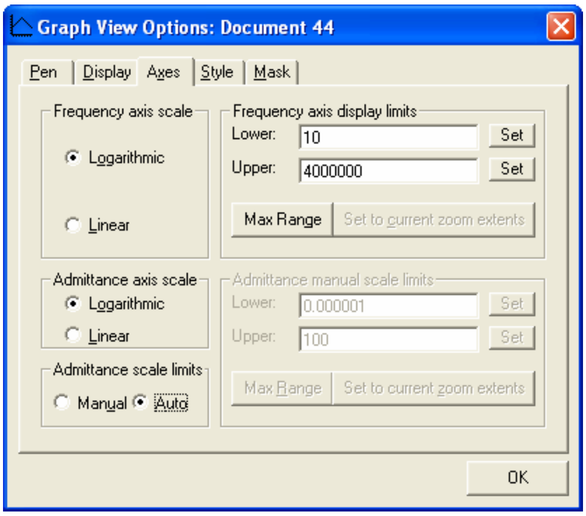


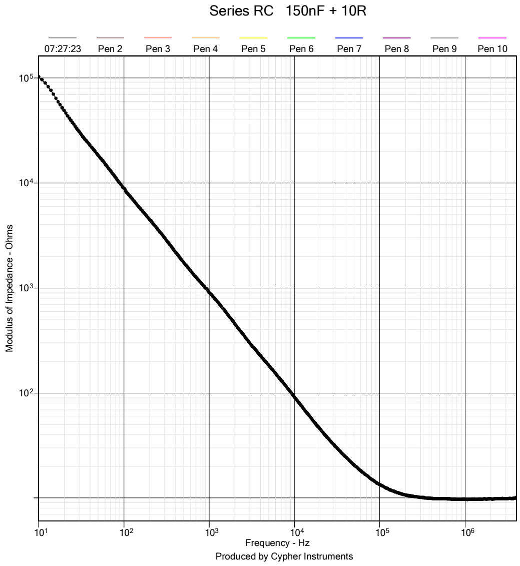


Now the graph is plotted on a linear frequency axis from 10Hz to 4MHz. All of the straight line slopes have been lost. Physical phenomena are usually best displayed on a log/log graph.

Next, go back to Impedance on a Logarithmic frequency axis. Click the Auto Scale dial. The graph is then auto scaled vertically between the maximum and minimum impedance values (below, right). There are no redundant vertical log decade cycles. This also operates in 'real time' when a test is being performed.

The Upper and Lower display limits can also be set by clicking the Manual dial. The values are then entered numerically.





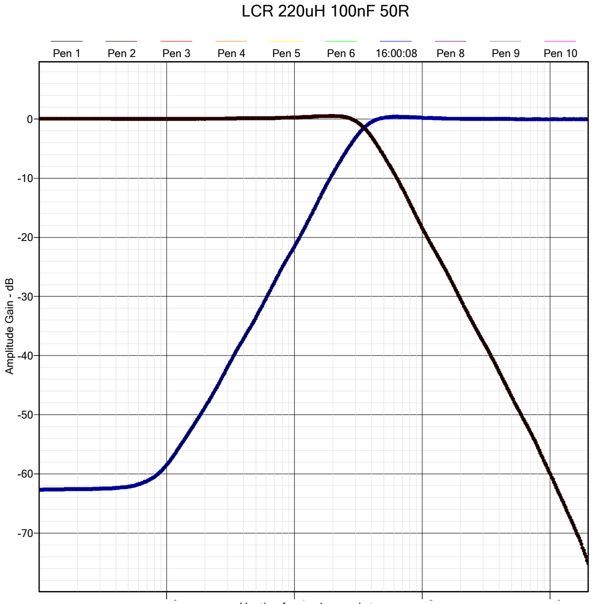
System Limitations

As with any measurement system the C60 has its limits. It is important that the operator is aware of these limits to aid accurate interpretation of the results. Because the C60 measures three parameters there are limitations associated with these. In many cases they can be reduced or eliminated by making changes to the test settings. Others are simply inherent limitations of which the user should be aware.

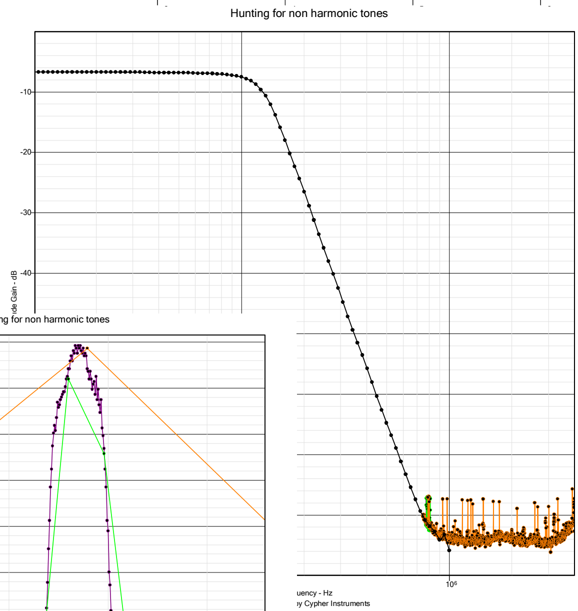
Harmonics

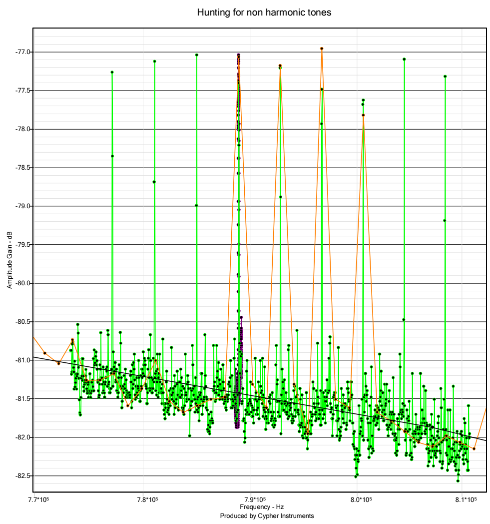
The sine wave generator contains harmonic, non-harmonic forms of distortion. The resultant waveform is not a pure sine wave. The non-harmonic components are sometimes referred to as *noise* because of their apparently random nature. These components can cause spurious peaks in the amplitude response of some systems. The sum of the distortion is about 62dBs below the sine wave level. However, the C60 has a 90dB dynamic range and can detect and plot low level distortion signals.

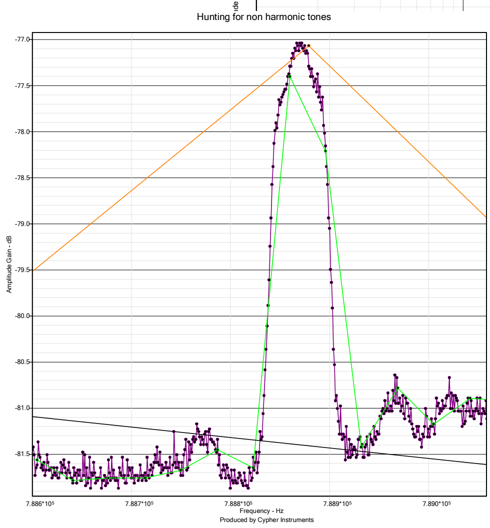
Distortion products can also change amplitude response graphs. A passive series LCR filter is tested in both its low pass and high pass configurations. The two responses (right) should be mirror images of each other. The high pass response has a low level shelf at about minus 62dBs. This shelf is the sum of all the harmonic components and distortion products that are not attenuated by the high pass filter, but which are generally removed by the low pass filter configuration.



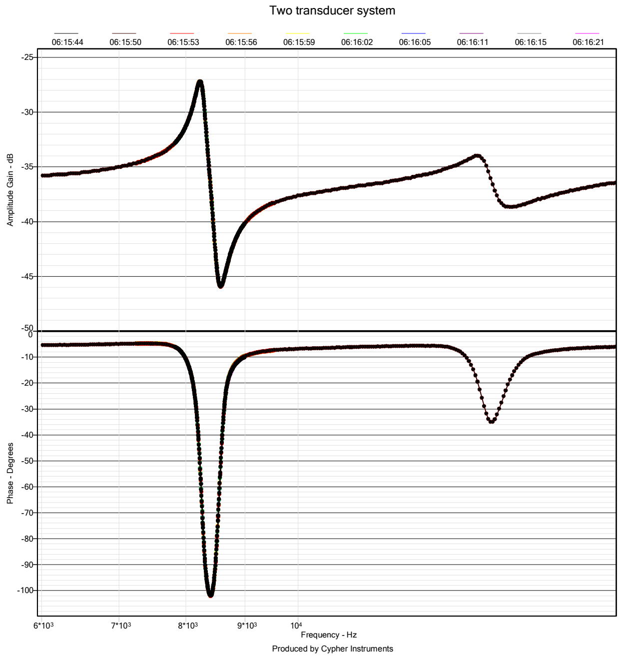
Another manifestation of the sine wave distortion is shown in this low pass filter (right). When the response is plotted with very fine resolution, there are some spikes in the stop band. These are low level, low frequency spurs that are produced by the sine wave generator. For example, at 800KHz there is a 400Hz spur at a level of -72dB. This is inside the pass band of the low pass filter and appears as a reading 4dBs above the -81dB noise floor. Zooming in reveals the fine detail (50Hz bandwidth) of these low level spurs (below, left and right).





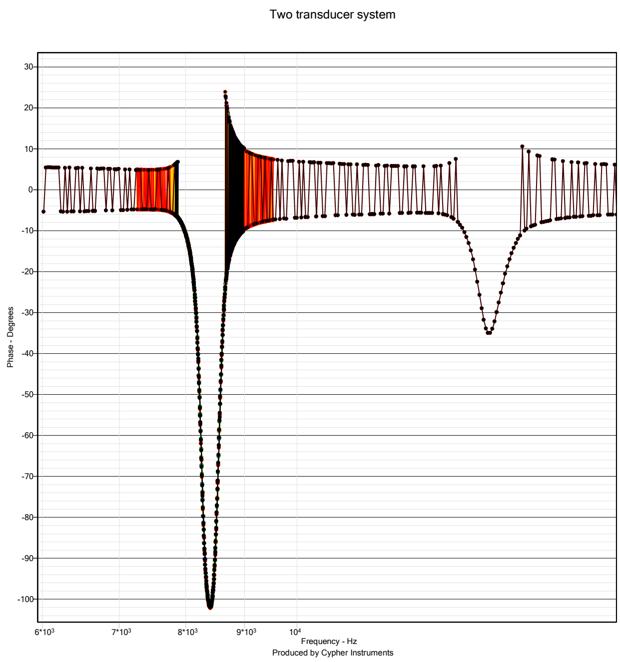


Phase detection

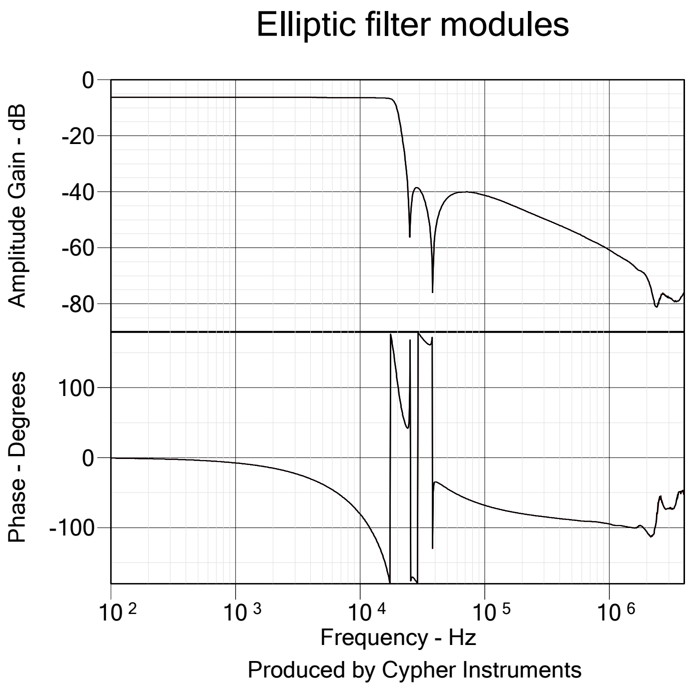


The next graph shows the amplitude and phase response of a two transducer system. One transducer is used as a transmitter, the other as the receiver. They are connected together by a resonant metal bar. The combined electro mechanical system displays low Q amplitude resonances and phase loops, all of which can be modified by external mechanical masses and damping mechanisms. The phase is plotted using a 180° display range. The amplitude response has no overall slope but has many resonance peaks and notches. This can result in the phase detection electronics being presented with a greatly attenuated test sine wave to which many amplified harmonic products are added. Under these poor conditions, the 180° display range gives the best phase plot (right).

When the phase is unwrapped to indicate a ±180° range, the presence of distortion products makes itself known (below). The sign detector, which does the unwrapping becomes confused and gives spurious results. This is the same phase plot as the one above.

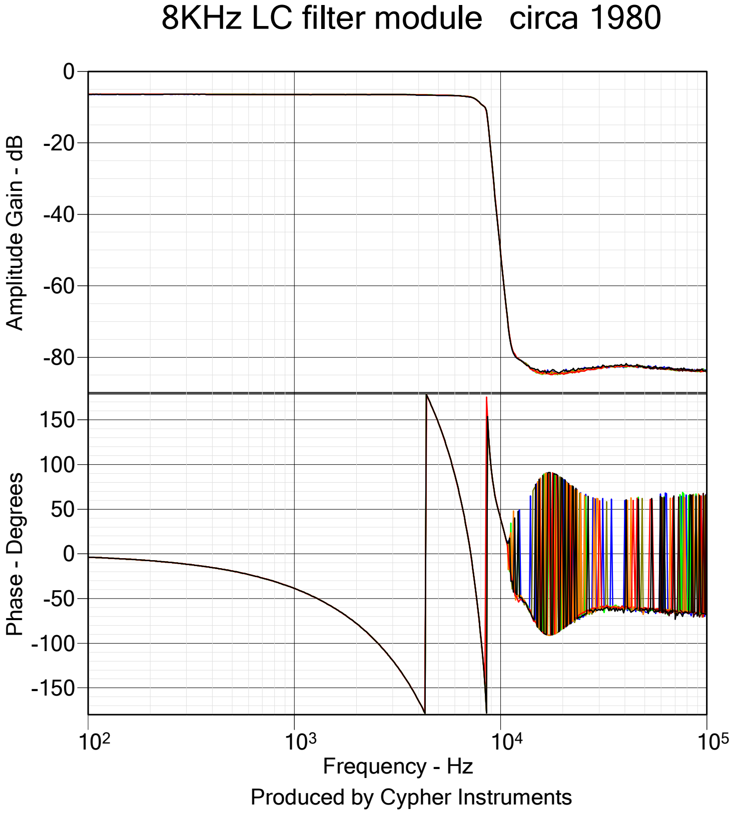


Phase detectors have problems resolving the transitions from ±0° and ±180°. On the graph, the ±180° transition is at the top and bottom of the picture, which makes it 'highly' visible. The ±0° transition is in the middle and so is less obvious. The 20KHz Elliptic low pass filter (below) demonstrates the phase unwrapping in action. In the region from 18KHz to 40KHz there are several ±180° phase transitions. At this part of the graph, the phase is moving very rapidly and so the transitions through 0° phase do not show any obvious aberrations. Slowly passing through 0° phase will usually produce a kink in the plot.



At about 2.3MHz, the signal level is very small (-80dB) and the phase and sign detectors produce big errors. The signal to noise ratio is terrible and the bandwidth requirements of the phase detector circuit are enormous. The phase plot under these conditions looks dubious.

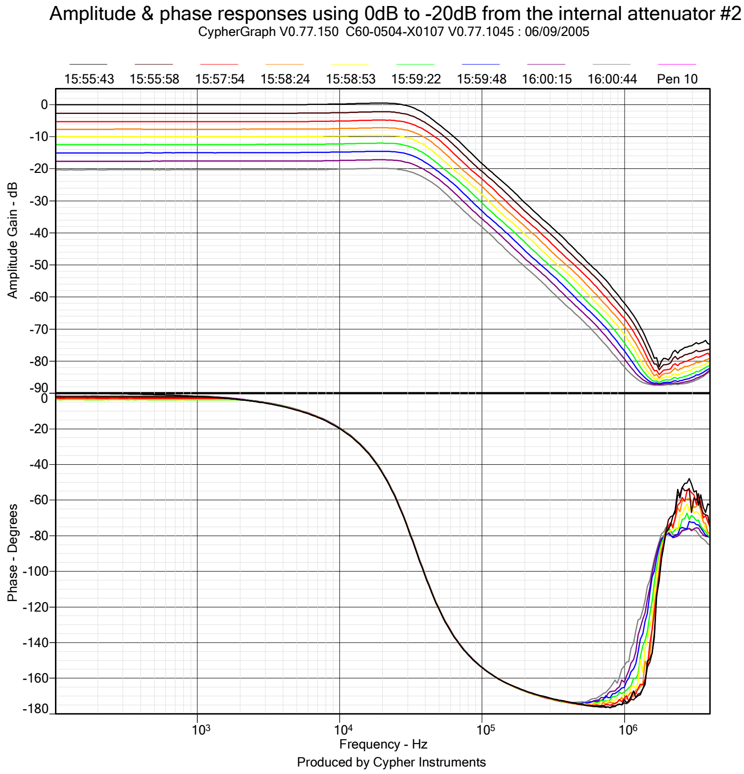
Another filter plot shows what happens to the phase detector when the signal level is very small. An 8KHz low pass filter module, which was built 25 years ago, still shows a good amplitude roll off (right). The phase detector does a couple of complete rotations before the signal is completely lost. The phase just seems to explode into a 'fuzzy' plot. Several plots are shown on the graph.



Phase accuracy

The phase accuracy is difficult to specify. It varies with test frequency, test level, signal attenuation in the DUT, interference and the frequency response of the DUT. Also, the sign detector that unwraps the phase, can find it difficult to perform well under all circumstances. The following two graphs exercise the phase detection system to reveal the operational accuracy.

In the first test, the C60 drives an LC low pass filter at 9 different signal levels. This will reveal any phase deviations that are associated with the variable test levels emanating from the C60. The amplitude graph shows 9 plots that track each other with a 2.5dB separation. Above 1MHz, the plots are compressed into the system noise floor. The phase plots track each other over a wide range. At 1MHz, the returned signal levels vary from -62dB to -82dB. These are very small signals and so the phase detector plots start to spread out. The signal levels at this frequency are 2mVpp to 200µVpp. These are not very useable signal levels. There is some phase information contained in the signal, but it is dominated by noise.

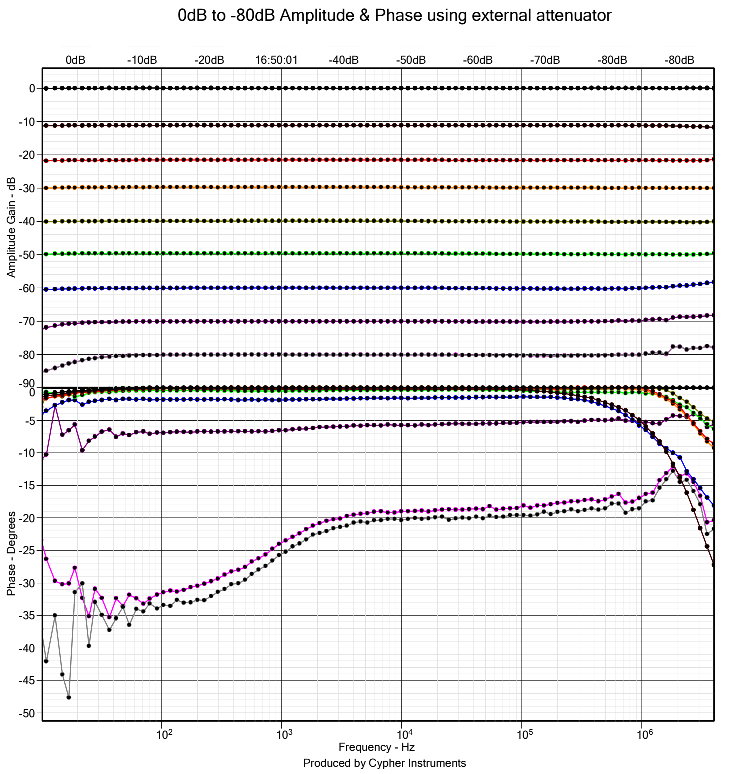


At the low frequency end, where the signal amplitudes are large, the phase deviates over a 3.6° range.

The phase detectors are calibrated at maximum signal level. If the signal is then subsequently attenuated, then the calibration is not valid.

The next test drives the output into the input via an external low impedance attenuator. This will reveal the phase deviation with respect to frequency, for 9 signal levels. Up until 1MHz, the phase deviation is below 3.0% for signals as small as -60dB. At -70dB, the error is 5.3% and at -80dB it meanders around from 25% to 10%. At -80dB, the signal level is 200µVpp, which is just about the limit of the phase detector. At this level, the phase results are very inaccurate. The amplitude detector has a larger dynamic range than the phase detector, so when the two are plotted on a graph, the phase response comes a 'poor second'.

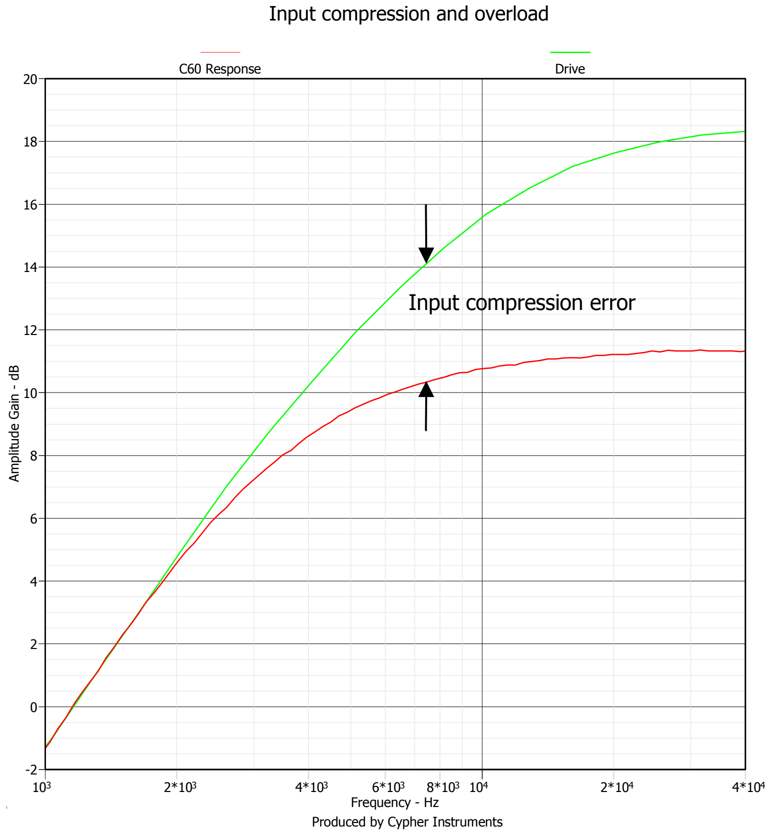
Another aspect of the phase plot is resolution. When the input signal has a good S/N ratio, the best resolution of the phase detector is 0.044°. This fine detail sometimes can be seen on the phase tails of first order filters. This is useful for revealing phase movements, but the absolute phase accuracy is much worse.



Dynamic range

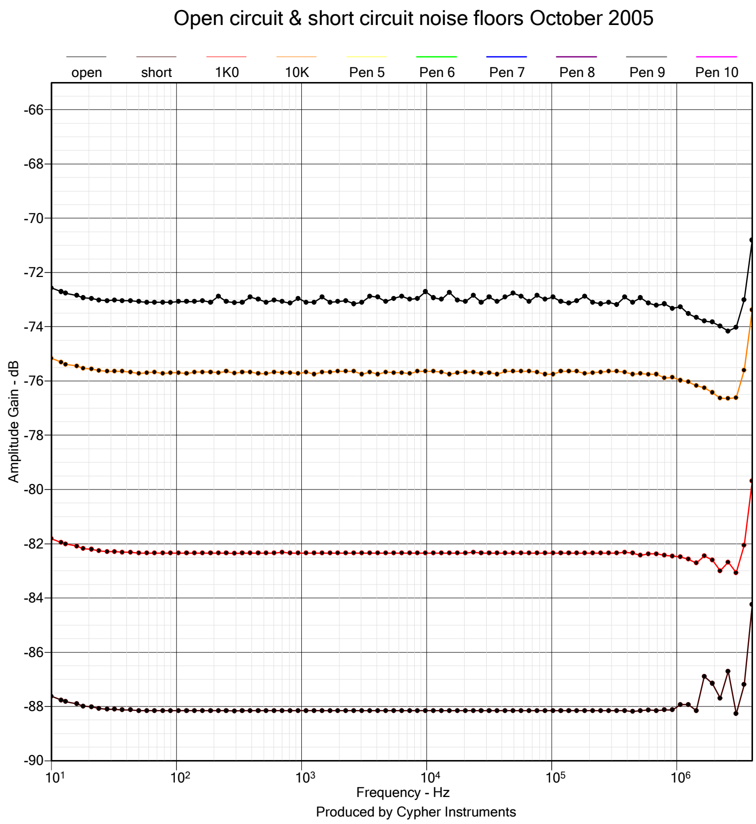
The C60 generates a maximum signal level of 2Vpp. This is the 0dB reference level on the Amplitude graph. For example a 200mVpp signal presented to the input of the C60 would produce a -20dB plot. Signals larger than 2Vpp can be presented to the C60. The input protection circuit causes signal compression (graph below). The green plot is the output of the C60 fed into a 10kHz high pass filter. This was then given +20dB of gain by an external amplifier and then fed back into C60, producing the input plot (red). The difference between the two plots is the input compression of the C60. When the input level is +5.0dB, the compression is about 0.5dB. For larger signals, the compression is correspondingly larger.

The input level limit for signal compression of less than 0.5dB is +5.0dB, which is a level of 3.5Vpp.



The input noise floor of the C60 determines the lower level for operation. A frequency response test, with the input of the C60 open circuited and then shorted, reveals both of these levels. The black plot is the open circuit (1Mohm) response. It is a true frequency response, because the unit has various internal cross talk paths that were painfully flattened out. Reducing the input impedance from 1Mohm, rapidly reduces the noise floor value. The minimum noise floor is obtained from a very low impedance input source, in this case a short circuit (brown). Also shown are noise floors for 10K (orange) and 1K0 (red) input source resistance.

The amplitude dynamic range of the C60 extends from +5dB to -87dB, although great care has to be taken to obtain this in an actual test scenario. A signal level of -87dB on this scale is 89µVpp, which is very small!



Time smearing

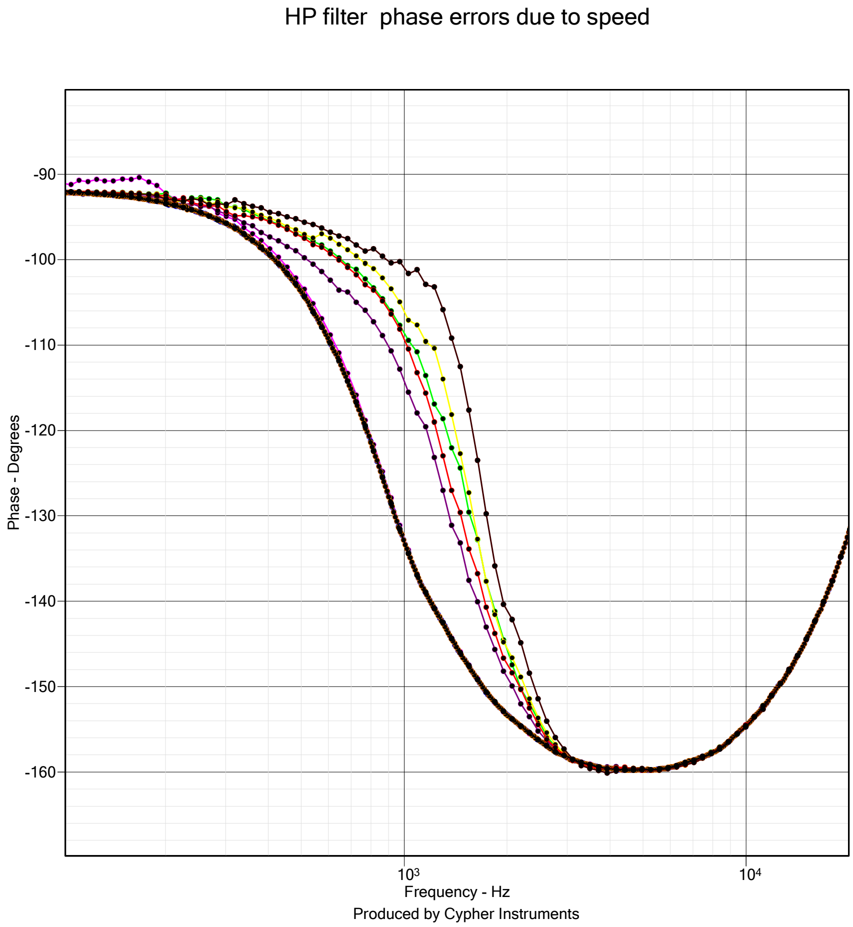
If tests are performed too rapidly, then the test signals may not be fully stable when they are converted into data. This results in time smeared plots. The phase detector has a time constant that is much longer than that of the amplitude detector and so phase is more sensitive to smearing. When performing a test, look at the graph and adjust the controls so that the phase plot is free of this effect.

Test speed is defined as the ratio change in frequency per data point. For example; testing from 10Hz to 1MHz (100,000 to 1) with 25 test points gives a 58.4% change per step (25th root of 10^5 = 1.584). This is a very large incremental change and is considered to be fast. Changing the test frequency by one point could cause a large phase or amplitude change in the DUT. These signals would take some time to reach new stable values. If they are read when they are still moving, then time smearing will happen. However, if 1024 test points are used over the same frequency range, the incremental change is only 1.1%. This is much slower, with much smaller changes in the data values.

A high pass filter was tested from 100Hz to 1MHz.using insufficient frequency points The phase loop shows signs of time smearing. The test frequency changes too rapidly so that the phase signal has not enough time to settle. When the test is redone using the maximum number of points, the graph is a consistent smooth curve.

For best results use at least 250 data points, and set the oscillator idle frequency to Test Start. Fewer data points with a long Test period could be used to allow the signals to settle, but more data points has the same effect and better resolution.

If the Repeat mode is being used, then use the Alternate A B frequency selection. This avoids a large frequency step during the 'fly back', which can introduce big transients into the system.



Impedance boundaries

Just like the amplitude measurements, the impedance range is limited by physical constraints. The output BNC and associated electronics has some unwanted properties. The ideal scenario would be that the output section of the C60 had no parasitic series resistance, capacitance and inductance, no parallel resistance and the electronics had no noise floor. Well, it's got all of these. The parasitic resistance and noise floors limit the low frequency minimum and maximum impedance measurements. At high frequencies, parasitic inductance increases the apparent impedance and conversely, parasitic capacitance decreases the apparent impedance. Also, the parasitic L and C components form resonant circuits with the test DUT's C and L components.

The C60 is small enough to be placed physically close to the DUT. In fact, it is important that tests are performed as close as possible to the C60. The output BNC connector has an resistance of approximately 5 milliohms when brand new (so take good care of it). If test leads are used, then they will add to the measured impedance. As a rule of thumb, one inch of 'straight' wire in air has an inductance of about 20nH. Cables with two conductors have capacitance between them of the order of 100pF per meter. The value depends on the cable construction. Cables also have series resistance. Connectors and test fixtures have parasitic capacitance and inductance. Great care must be taken when measuring impedance, otherwise you can end up with misleading plots.

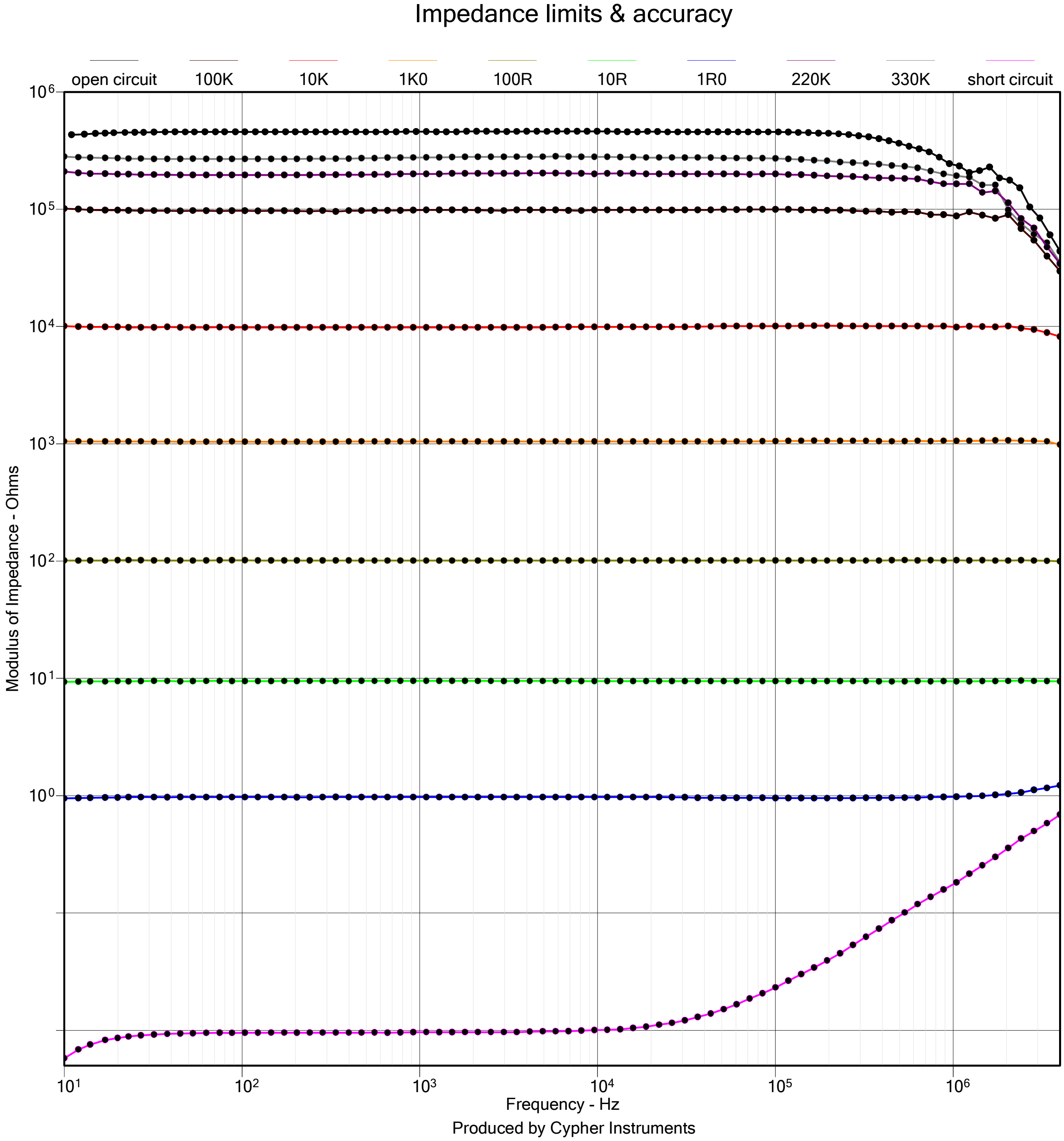
Some impedance analysers use a four terminal method of driving the DUT. The DUT is driven by two voltages, V-High and V-Low. Then, two terminals are used to measure the voltage difference across the DUT, C-High and C-Low. The 'C' refers to the Current terminals that you would get on a four terminal 'current sensing' resistor. By using this method, the parasitic components of the analyzer can be largely removed from the test by making the measurements at the DUT terminals. This is at the expense of having four cables connected to the DUT and extra reactive components in the system.

The C60 has a stray inductance of 23nH and a stray capacitance of 33pF. These reactive components will resonate with any counterparts that they are connected to. Also, they form part of the maximum and minimum impedance measurement boundaries.

The C60 impedance performance was tested (below). With an open circuit, the C60 reaches a maximum reading of 450K. This is the upper boundary of the unit set by internal noise floors of the electronics. The upper boundary is a compressing limit. A 330K resistor reads 271K, an error of about 18%. A 220K resistor reads 196K, an error of about 11%. Lower resistor values have virtually no significant error. The upper boundary was measured using the maximum output signal level. If the signal level is reduced by 20dBs, then the point at which the noise floor equals the signal is also reduced by the same amount. Lowering the signal level, lowers the maximum impedance readings.

The lower impedance boundary is limited by the C60's output resistance and inductance. This is nominally a 10 milli Ohm resistive boundary at low frequencies. The output inductance causes the high frequency impedance lift. The slight droop at 20Hz/0.01 Ohms is caused by measurement errors in the C60.

The measured low frequency impedance boundary range (below) is 457k to 0.01R. This is a continuous dynamic range of **45,700,000 to 1** (**153dBs**).

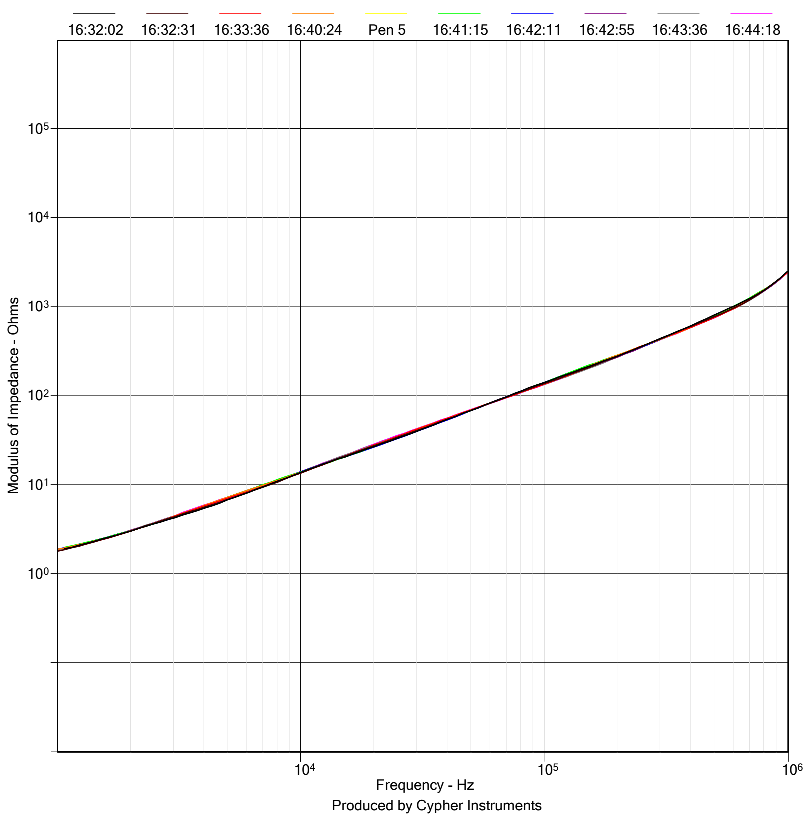


Impedance accuracy

When an impedance test is performed on a single reactive component, the theoretical slope should be a straight line with a slope of ±6dB_Z/octave. In the C60, the electronics that measures impedance has a small cyclic deviation from a straight line performance. This results in an undulating error when measuring impedance.

A 220µH inductor was tested with 9 signal levels from 0dB to -20dB. The resulting graph (right), shows a slight variation in the plot width. Ideally this graph should be 9 plots, all having exactly the same data points. However, the variable signal level reveals the errors in the detection system. The detector operates continuously over a 7 decade range and so some compromises are bound to be expected.

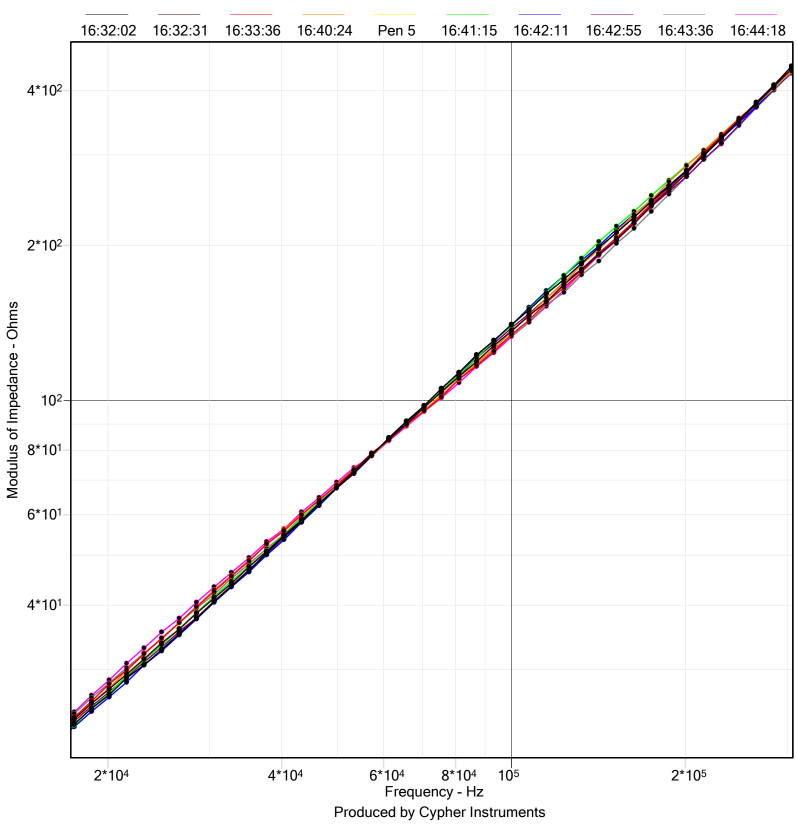
0dB to -20dB from the internal attenuator, driving 220uH



When we zoom into a small area of the graph, the errors become more visible. The impedance plot shows the cyclic nature of the deviation. At 60kHz the deviation is almost zero. At about 120kHz, the deviation reaches a maximum with a ±4.5% error.

This phenomenon can be seen on inductor, capacitor and tuned circuit networks. With only one plot, it manifests itself as a slight undulation along the slope. When the network is tested at a variety of drive levels, the deviation is more visible.

0dB to -20dB from the internal attenuator, driving 220uH

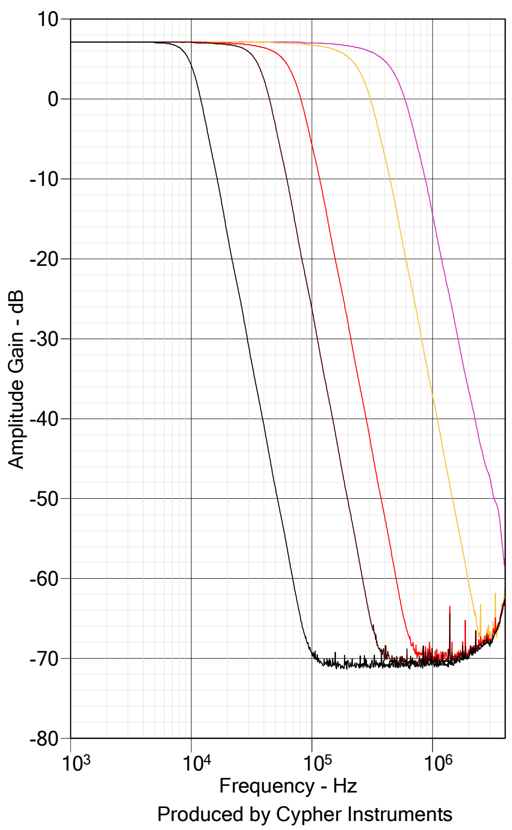


Applications Notes

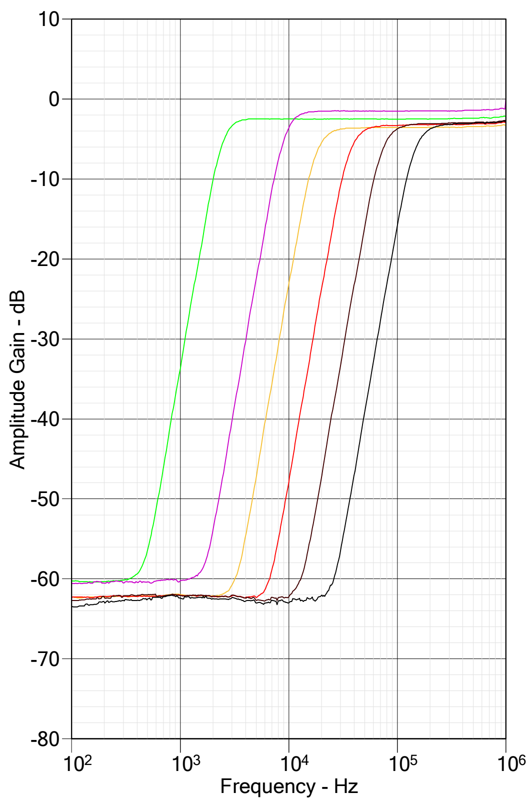
Filter responses

Some continuous time filters were tested (below). These filters have digitally selectable cut off frequencies.

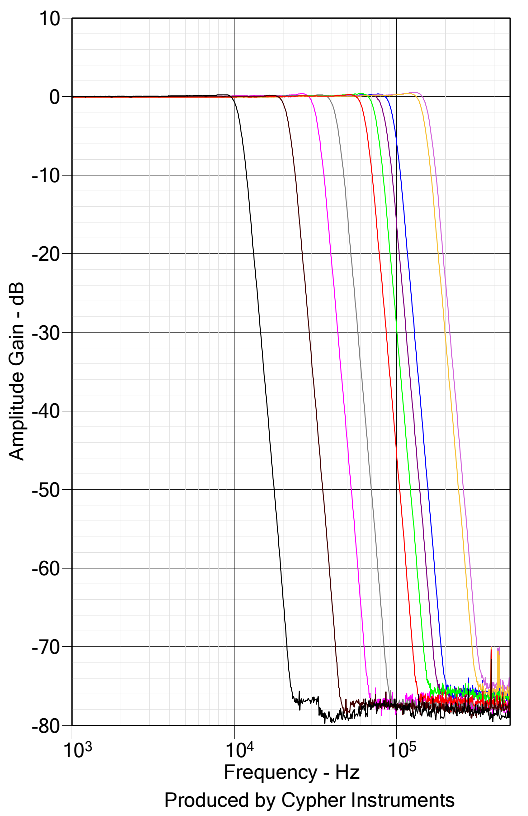
Low pass 4th order



High pass 4th order



Low pass 8th order



The 4th order low pass filter has a pass band gain of +7dB, and a noise floor at -71dB, giving it a dynamic range of at least 78dB.

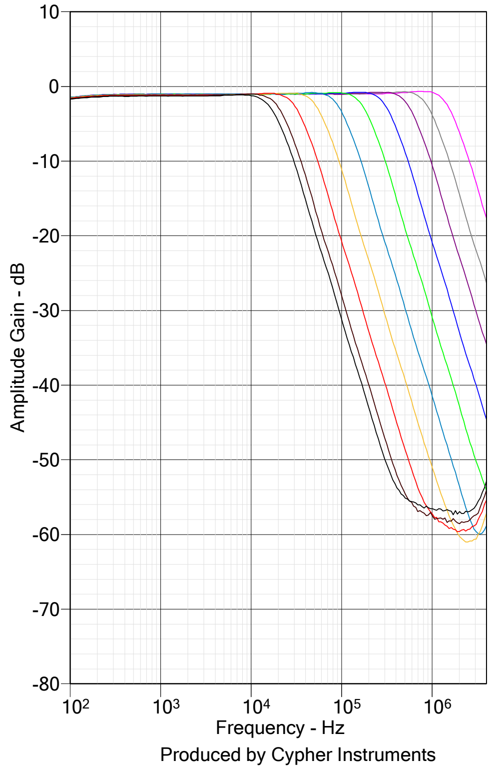
The high pass filters have a low frequency shelf at about -60/62dB. This is caused by the quantization noise of the digital sine wave generator.

The 8th order low pass filter shows a much more dramatic roll off slope than the previous graphs. The noise floor is shown at about -76/78dB. Some of the high frequency spikes in the stop band are low frequency spurs from the sine wave generator that are passed by the filter. They reveal the performance of the sine wave and not the filter.

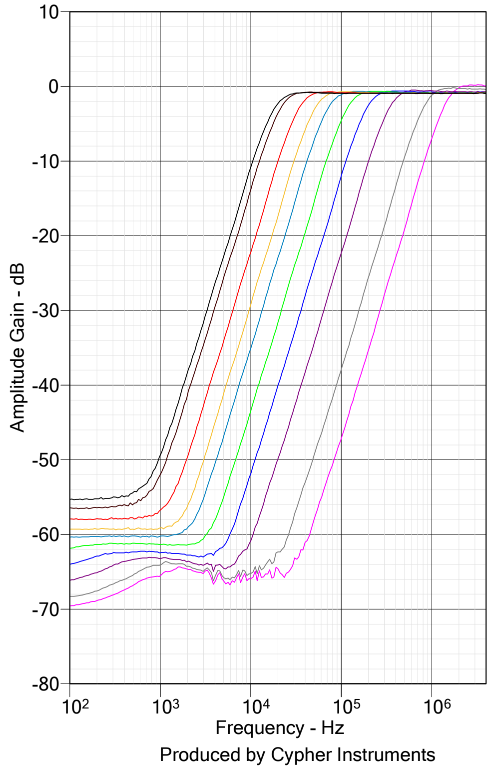
The graphs on this page were exported as meta files with a portrait aspect ratio, to match that of the paper.

A voltage controlled state variable filter with a '100 to 1' control range was tested (below). This filter has simultaneous low pass, high pass and band pass outputs. By mixing HP and LP outputs, a range of notch responses is generated. This filter has a continuously variable tuning range from 19KHZ to1.5MHz.

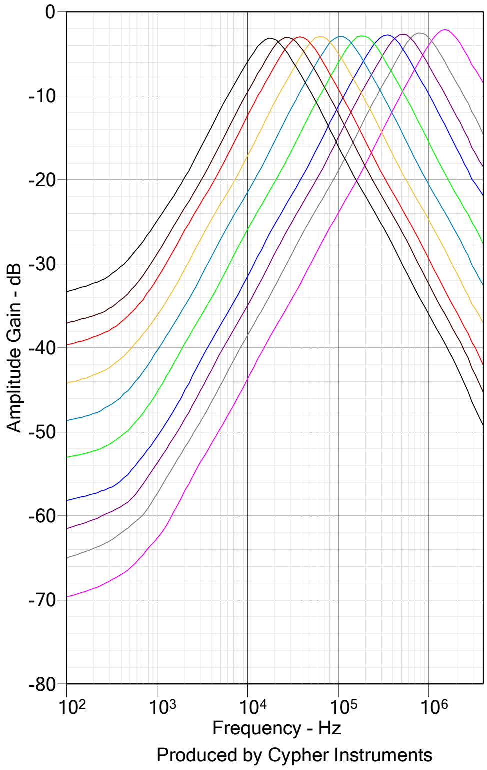
Voltage controlled filter LP 19KHz - 1.5MHz



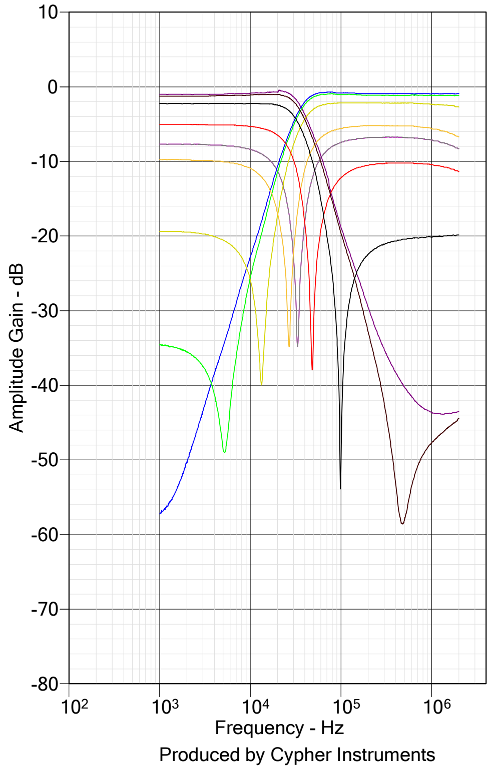
Voltage controlled filter HP 19KHz - 1.5MHz



Voltage controlled filter BP 19KHz - 1.5MHz



Voltage controlled filter notch 19KHz - 1.5MHz

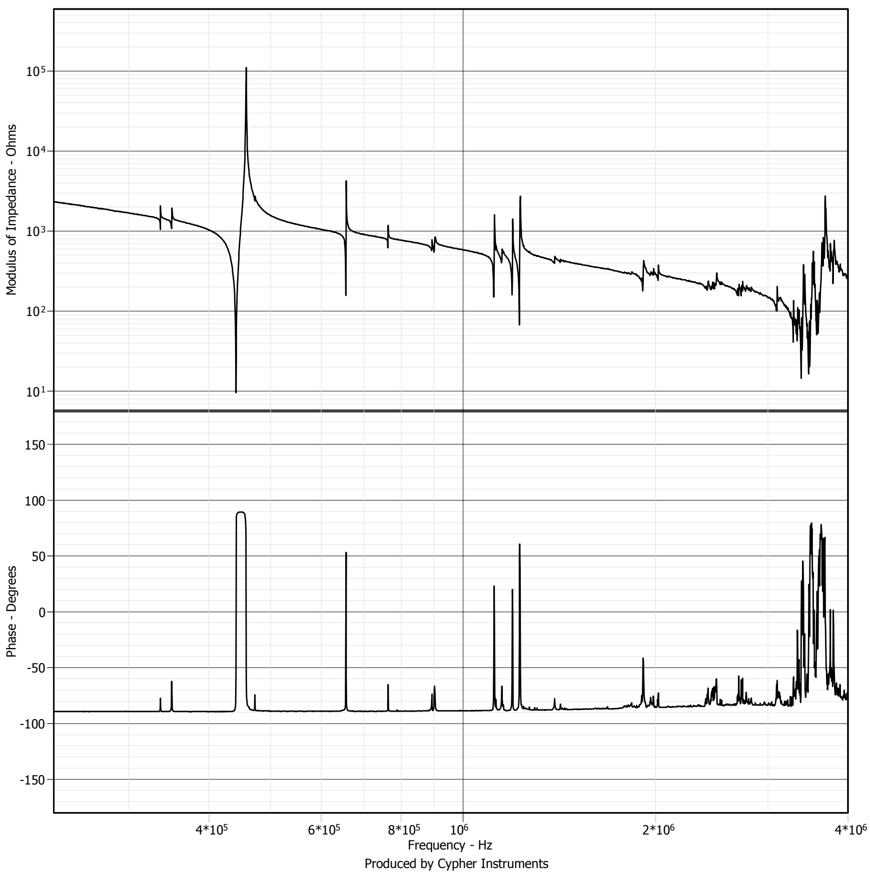


Ceramic resonators

Ceramic resonators are used in electronic circuits to generate tuned oscillators. They are not as accurate or stable as quartz crystal oscillators, but they are small and inexpensive. Their resonance modes are determined by surface acoustic time delays.

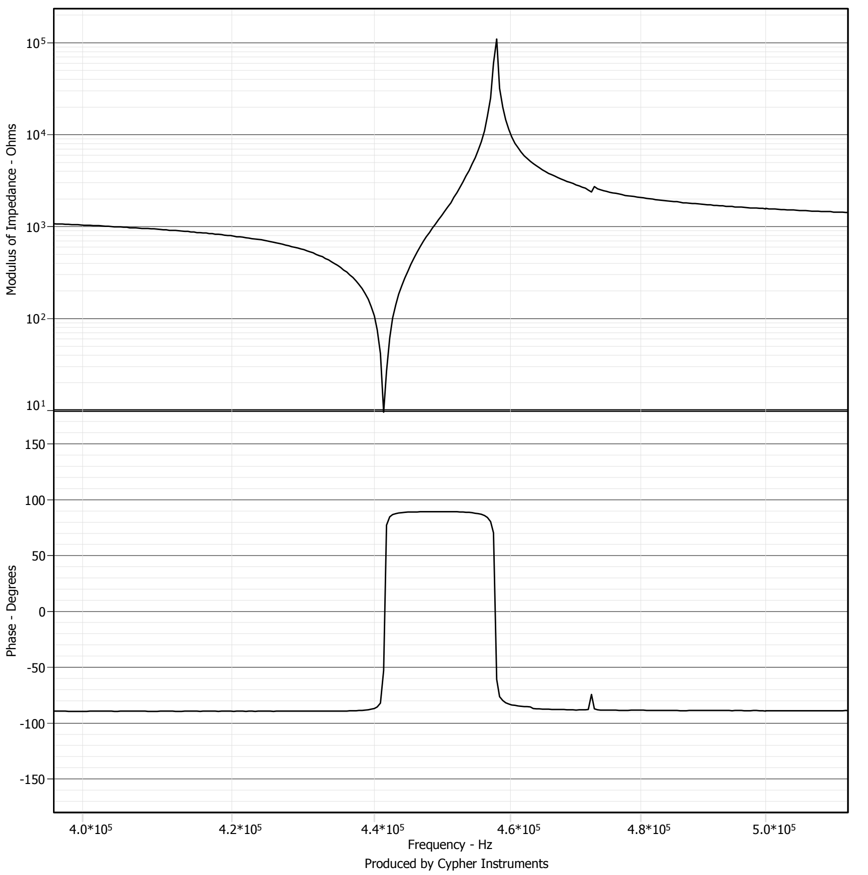
A 455KHz resonator was tested (right). It exhibits many resonance modes, including a major dip and peak at about 455KHz. The device has the general impedance slope of a capacitor and produces a -90° phase shift for most of the frequency range. However, at resonant frequencies the phase shift moves towards +90°. The resonance at 455KHz shows a classic phase loop.

455KHz resonator, complex impedance



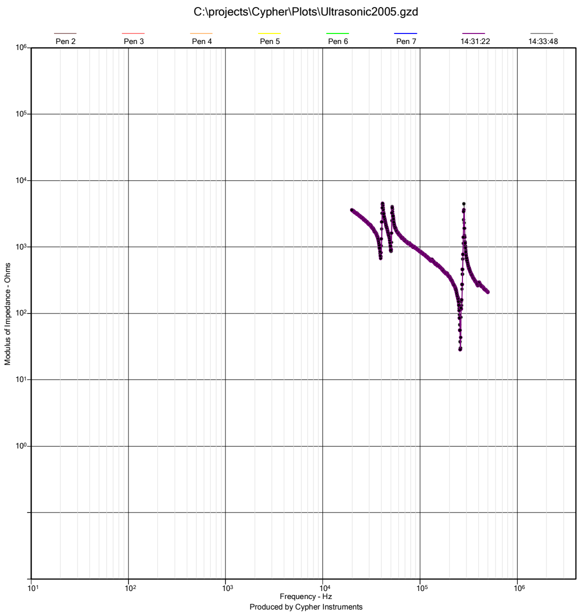
The resonator was retested from 420KHz to 480KHz. The phase loop is revealed in much greater detail, showing a ±90° range. Note also, that the impedance changes from 5 ohms to 20,000 ohms.

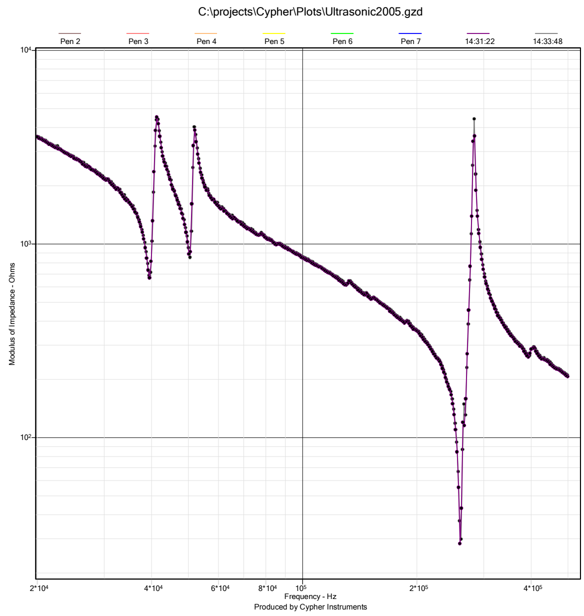
455KHz resonator, complex impedance



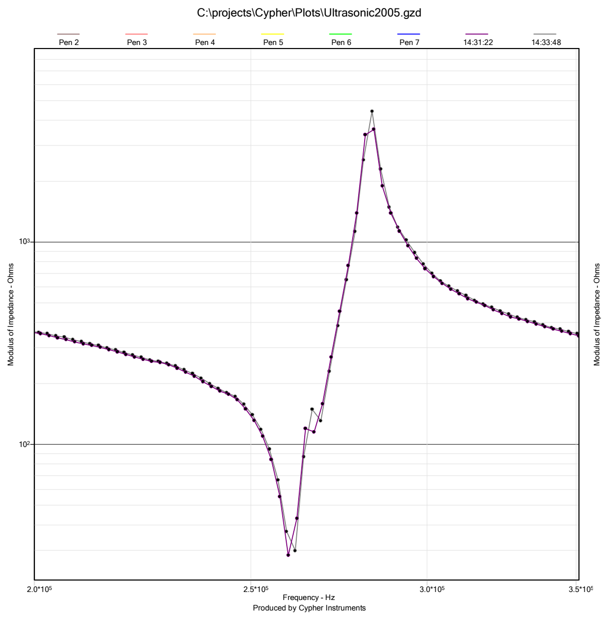
Ultrasonic transducers

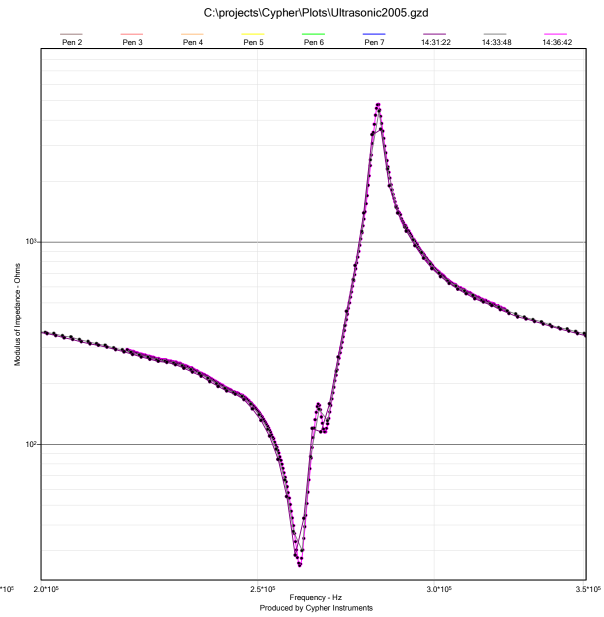
A 40KHz ultra sonic air transducer has a very interesting impedance response. The device is constructed from a circular diaphragm that is riddled with dramatic resonance modes. The transducer was tested from 20KHz to 500KHz. Over this range, the impedance varies from 200 ohms to 5K. When zoomed in, there is a classic impedance curve (a series resonance followed by a parallel resonance) at 40KHz. But there is not just one, there are also many others.





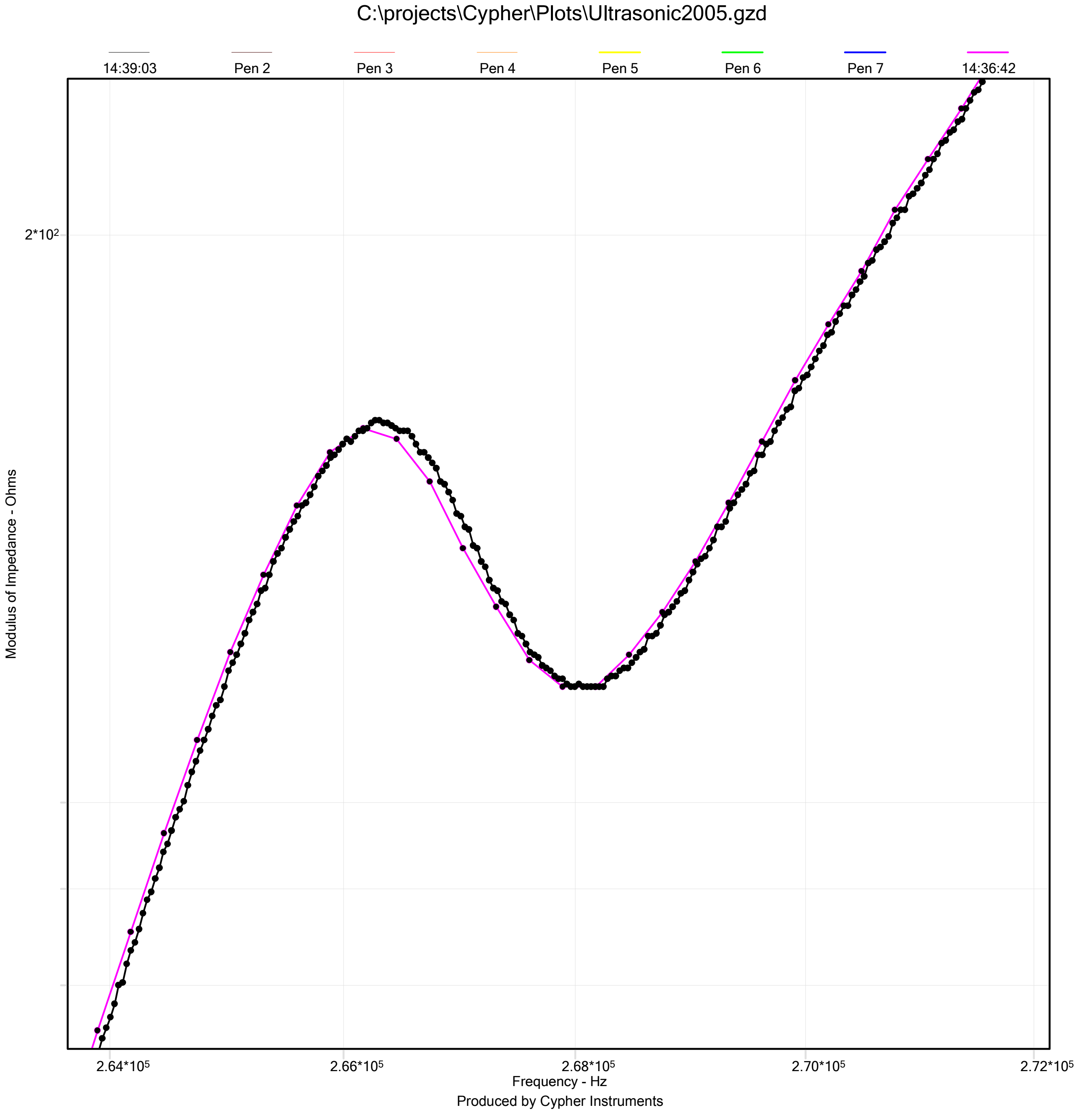
There is a major resonance at about 270KHz. Zooming in on this, we can see that there seems to be another small resonance in between the minimum and maximum impedance. However, there are not enough sample points in the plot to clearly reveal the response of the device. The transducer was retested using the 'Use X axis extents' facility. The plot now has many points, enough to show the smaller resonance in finer detail.



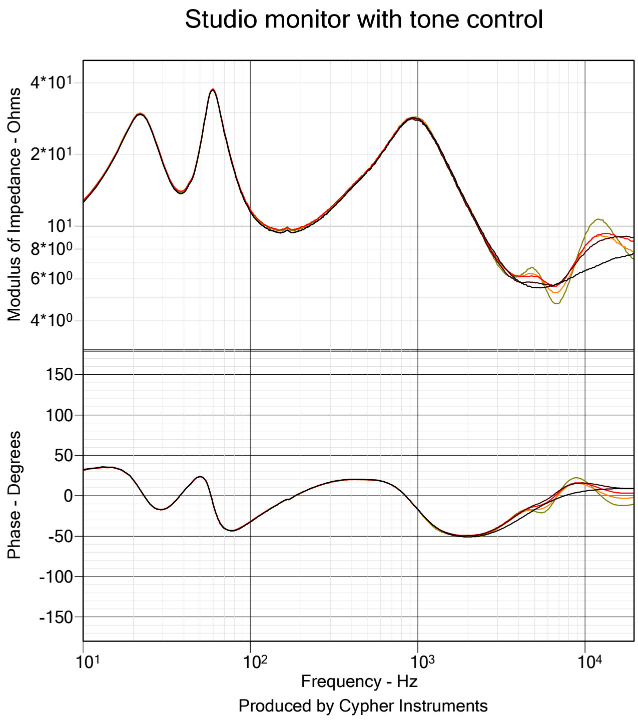


Again, the 'Use X axis extents' facility is used to further zoom in and retest the response of the transducer.

Now the response is starting to look rather crunchy and ragged. This plot is now showing the noise floor and quantization gremlins of the test system. Further zooming in will reveal more about the electronics of the C60 than the response of the transducer.



Acoustic transducers



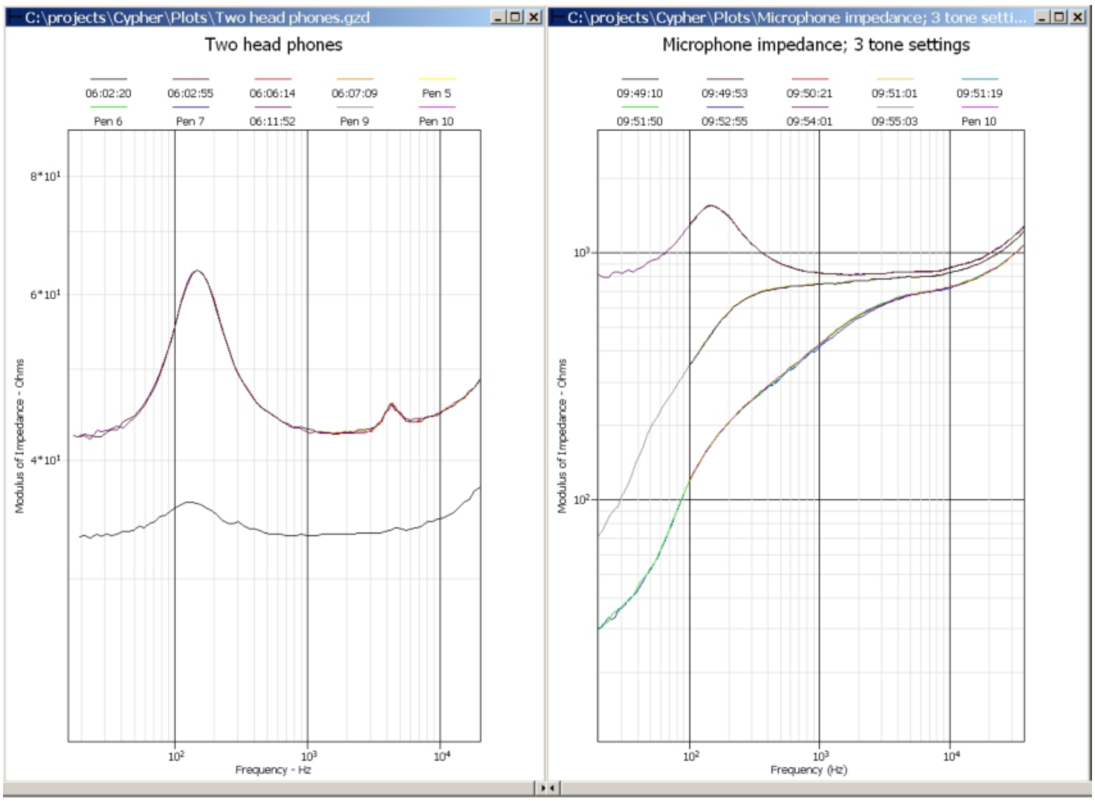
A more common acoustic transducer is the humble loud speaker. Probably there are more of these on this planet than there are people. The nearest one to hand, with a cable attached is my '8' ohm studio monitor with 2 speakers, a cross over and a passive treble control.

The impedance varies from 4.5 ohms to 35 ohms. Also, the high end impedance varies as the passive tone control is adjusted. The impedance & phase plots reveal the horrors of driving reactive power loads. The phase shift is between ±50°, which is moderately dramatic. Imagine if it were ±90°. This would mean that for certain frequencies the current phase would be orthogonal to the voltage phase. Put another way, the power amplifier driving this load would have to deliver peak current when its output voltage was zero volts. *I have trouble imagining this.* Also, this peak current is extracted at the amplifier's distortion cross over point.

Some more impedance plots are shown below. Two head phones were tested, revealing the usual low frequency peak. Also, a microphone with a three position passive tone switch, used to select different audio responses. Both are electro acoustic transducers and their roles can be reversed. A microphone can be used as a speaker and visa versa. This is common practice in ultrasonic pulse echo systems.

Remember that when testing acoustic devices, noise in the test room is turned into electrical energy. This is an interfering signal, just as much as magnetic and electric interference is to electrical circuits. The C60 does not know what it is doing. It treats all signals as the truth.

The two graphs were 'tiled' and screen captured, so their shape is not the usual square aspect ratio

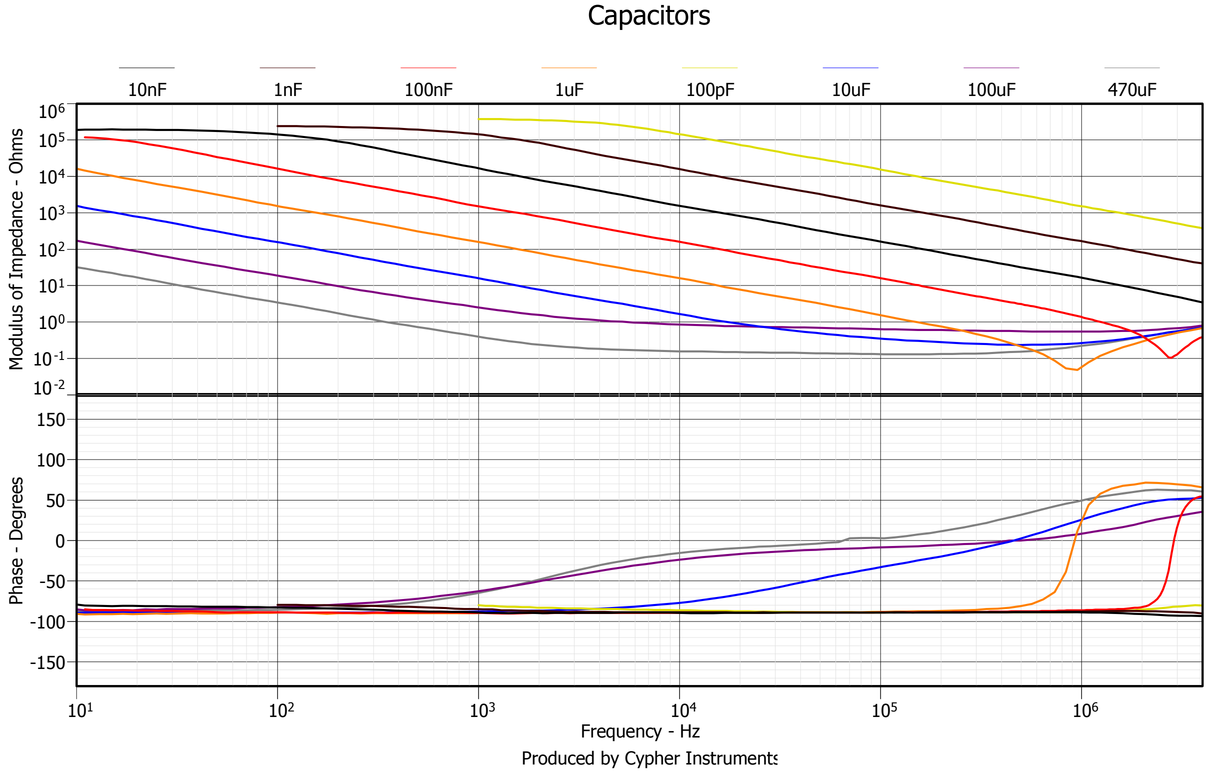


Simple reactive components – L C R

Capacitors and inductors have a reactance that varies with frequency. They also suffer from parasitic effects that degrade their theoretical performance. Inductance and capacitance store magnetic and electric energy respectively. When these two combine they form resonant circuits.

The following tests were performed on capacitors and inductors with axial leads. These leads add parasitic inductance and resistance to the part being tested.

Eight different capacitors were examined. The yellow trace is a 100pF ceramic capacitor. The subsequent values are 1nF (brown), 10nF (black), 100nF (red), 1uF (orange), all plastic film. Then, a 10uF (blue), tantalum bead. Next, a 100uF (mauve), regular electrolytic can type. Last, a 470uF capacitor (grey), a low impedance electrolytic can device.



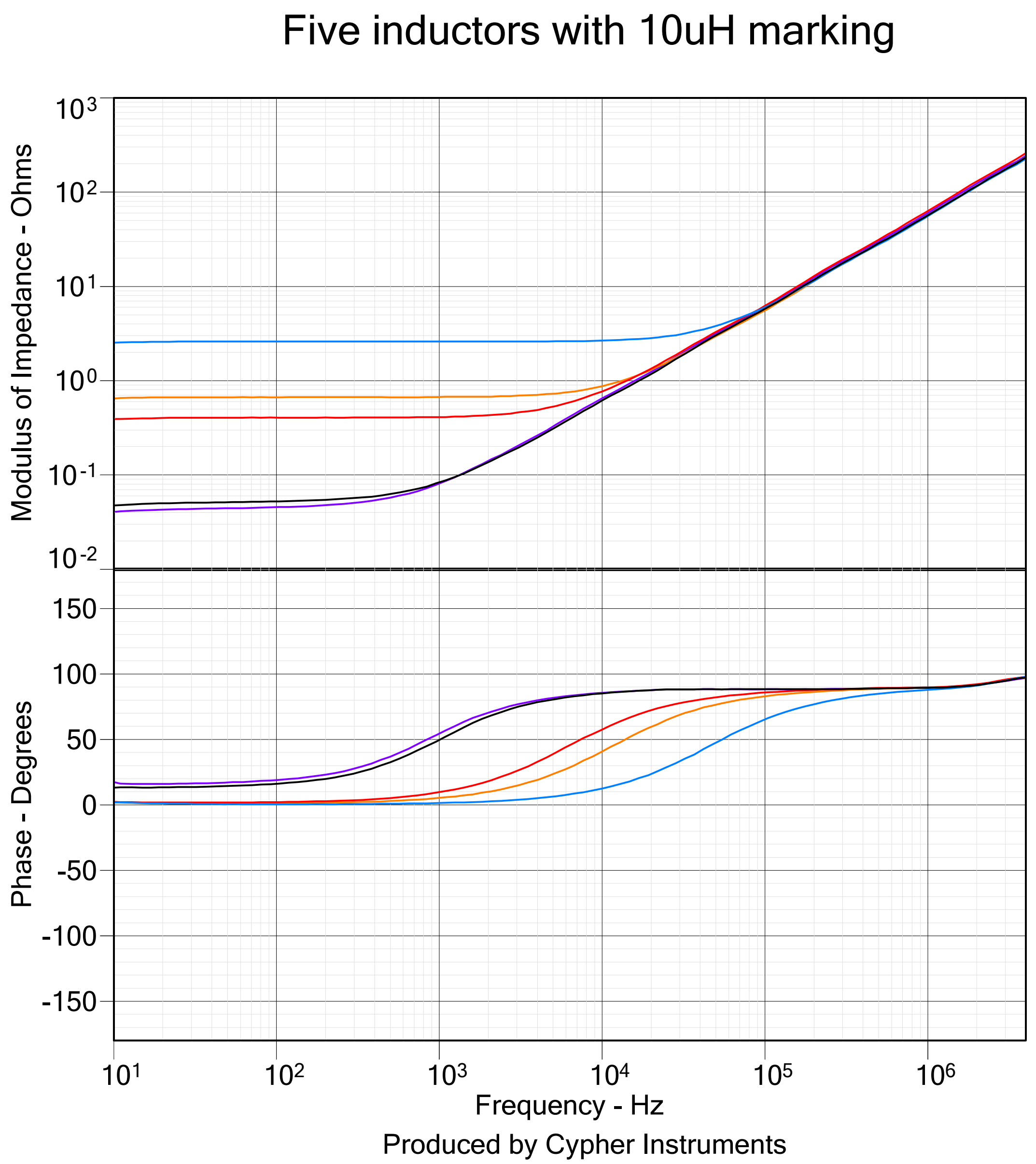
The 1uF and 100nF capacitors show resonances at 1MHz and 2.7MHz. This is a mixture of self resonance and the parasitic inductance in the test setup. The complex impedance graph reveals the capacitive, resistive and inductive portions of the DUT response. A capacitor has a -90^{o} V/I phase shift. An inductor has a +90^{o} V/I phase shift.

The plots show that ceramic and plastic film capacitors with wire leads and other forms of stray inductance, will form series impedance resonators. At frequencies past this resonance, they 'look' inductive, which is displayed by the phase jump. They have a rising impedance plot and a current phase reversal. To avoid resonances with capacitors, use surface mount parts (no leads), use short thick tracks and use a ground plane (the parasitic inductance is proportional to the loop area of the conduction return path). A ground plane will reduce stray inductance, but will increase stray capacitance, which is another problem. Also, to reduce stray capacitance, make tracks as small as possible, break up or cut out parts of the ground plane under these tracks or use a ceramic board or a board with low dielectric value. Ordinary fibre glass (FR4) has a value of 4; that is it is 4 times better than a vacuum at making capacitors. FR1 dielectric has a value of 1. To reduce both L and C parasitics, make everything as small as possible.

The 10uF tantalum capacitor has a characteristic flat response. For much of the response, its impedance curve is better than the 100uF electrolytic capacitor. The *low impedance* 470uF capacitor has, as its name suggests, the lowest impedance response, making it ideal for the bulk of a power supply reservoir. At high frequencies, the stray inductance causes a rising impedance plot.

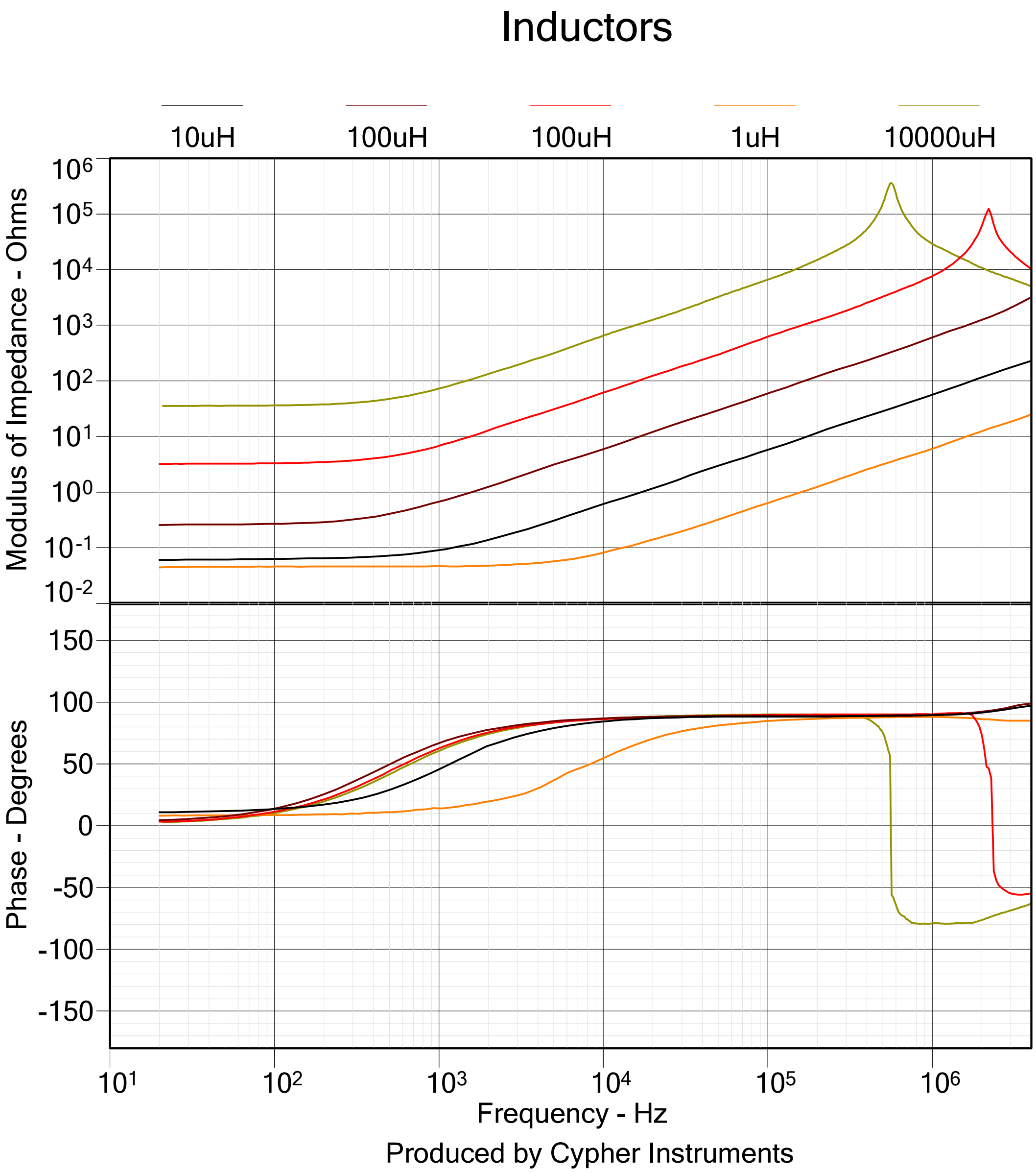
Capacitors have other parameters to consider. They have temperature coefficients. The Y5V ceramic dielectric has an enormous coefficient, where as COG and NPO are really quite stable. Some capacitors change value with applied DC voltage. They also have a parameter called ESR, Equivalent Series Resistance, which may cause overheating and explosive rupture when used to filter or couple power; see the 100uF electrolytic.

Five inductors with the same value (10uH) printed on them were tested by the C60. The results show that they all have the same basic response at high frequencies, but not at low frequencies. The low end impedance varies by about 50:1. This is a caused by different winding resistances used in the construction of the inductors. Magnetic materials also have their own frequency response, quite apart from the definition of reactance for an inductor { $X_L = 2\pi fL$ }, which assumes that the value of the inductor is invariant with respect to frequency. For example, soft iron works well at low frequencies. However, ferrites are produced for selected high frequency operation.



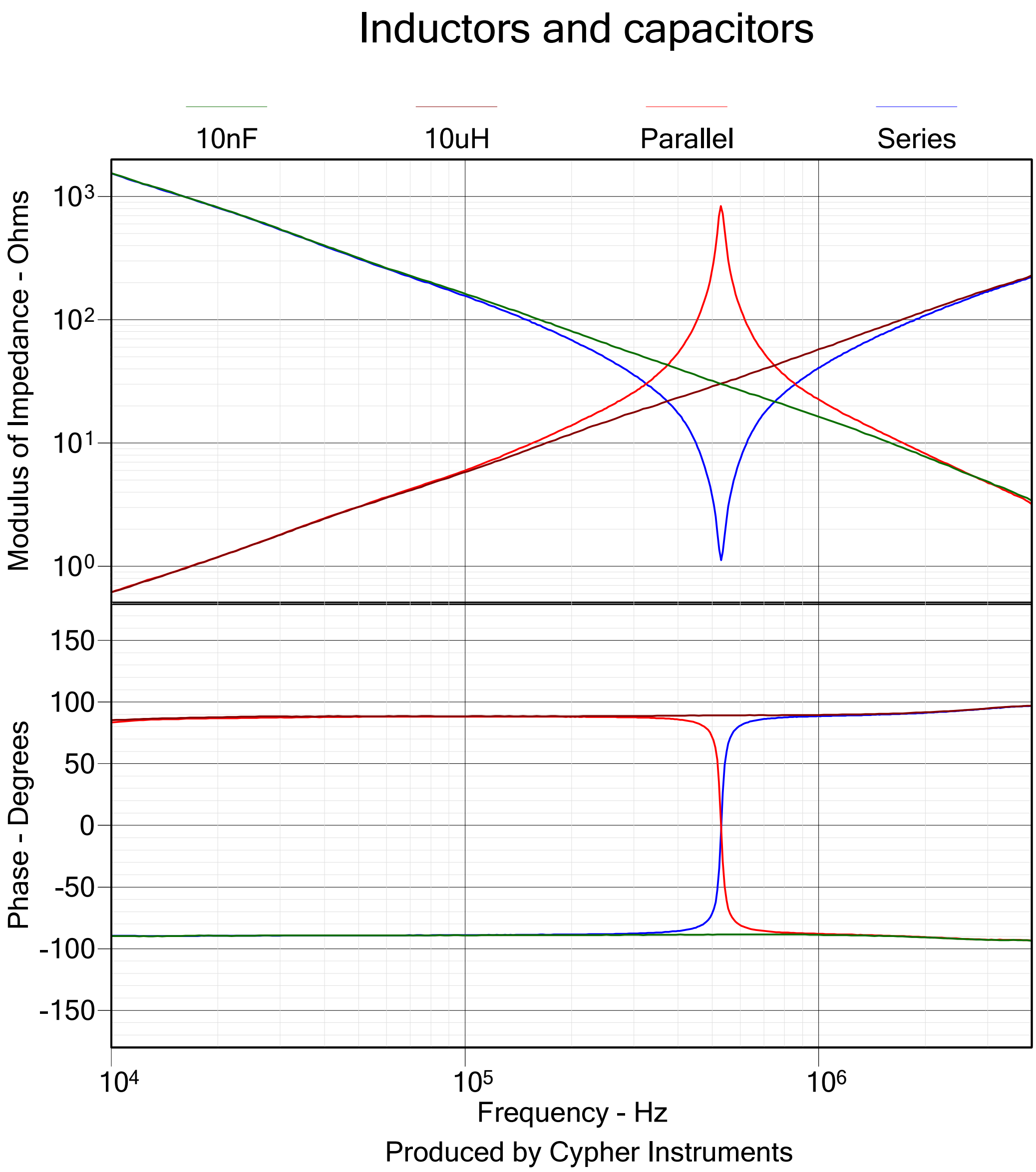
The phase shift is +90° when the impedance is dominated by the inductive reactance. When the winding resistance becomes significant, the phase shift tends to zero.

Eventually, all inductors will self resonate or resonate with external parasitic capacitance. Five inductors, 1uH, 10uH, 100uH, 1mH and 10mH were tested (below). Their impedance plots show low frequency shelving caused the winding resistance. This is an important consideration if they are to be used as passive power filters. The power dissipated by the resistance defines the maximum safe current allowed through the part. Their inductance may also vary with DC bias current.



At high frequency, resonance occurs. Any stray capacitance forms a parallel LC resonator which causes an impedance peak. It also causes a phase reversal. This is called the self resonant frequency of an inductor. Past this frequency, it has the characteristics of a capacitor. At this frequency it behaves like a parallel resonator. Even below this frequency it doesn't behave much like a pure inductor. In this example, the inductors are 'inductive' over a three to four decade range. If you want to use an inductor in a tuned circuit, be certain that the self resonant frequency (SFR) of the inductor is much higher than that of the circuit.

In the previous text, 'pure' inductors and capacitors turned out to be less than perfect. Their parasitic components produced self resonance. Below are examples of intentionally tuned circuits which are constructed from discrete inductors and capacitors. In the example, a 10nF capacitor and a 10uH inductor are used to construct resonant circuits. The downward sloping line (green) is the impedance plot of the 10nF capacitor. The rising slope (brown), is that of the 10uH inductor.



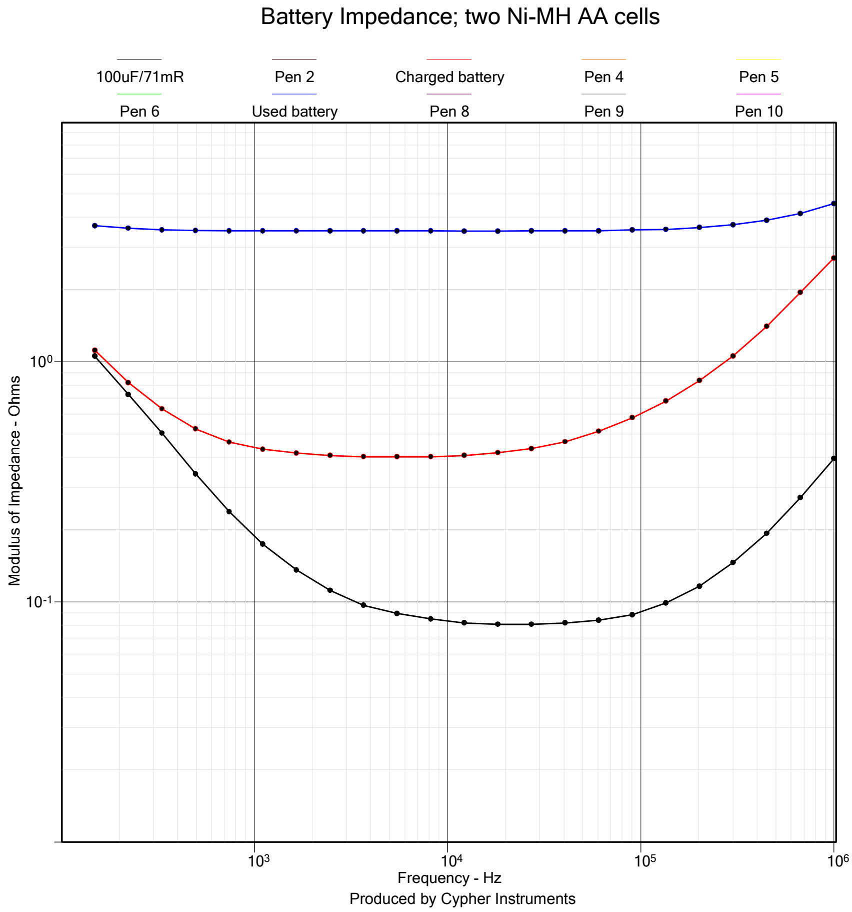
When the two components are wired in parallel (red), the impedance has a peak response at resonance. When the two components are wires in series (blue), the impedance has a minimum response at resonance. The phase plots indicate the transition through resonance. The resonant frequency happens at the intersection of the L and C impedance plots. That is, when $|Z_L| = |Z_C|$, resonance will occur.

These plots look like amplitude response graphs. They have the same general characteristics, such as 20dB/decade slopes, but they are representations of what is happening in the impedance domain.

Battery impedance

There are many types of battery. Some have relatively flat output voltage discharge curves, others have large variations. Some are rechargeable, others not. Some self discharge with enthusiasm, others have a good shelf life. They all suffer from similar problems. Their output voltage drops with discharge. Also their internal impedance increases with discharge and with the number of times they have been recharged.

To date, there does not seem to be a reliable method of measuring the energy stored in a battery or the available time left before the electrical demand collapses the power supply. Electronic gas gauges, so called because they emulate the *gas*oline tank in a car, try to measure the charge in the battery as if it were a 'liquid'. Coulombs (the liquid) are counted in and they are counted out. In this way, a gas gauge is constructed. However, internal battery self discharge (a leak), defeats the measurement system. The battery is overfilled on charge, which usually gives a 50% error on start up. Also, as the battery capacity reduces with recharge cycles, it becomes more difficult to predict how much charge is left at any point in time. Even if the gas gauge actually worked, it does not measure output impedance. The gas gauge could say, 'there is 40% capacity left in the batteries'. However, the output impedance might have increased by a factor of 10. If a high current demand happens, such as the charging up of a photo flash circuit, then the battery voltage will suddenly dip causing a micro controller reset. It happens all the time. You go to take a digital photo, you press the shutter switch and the camera turns itself off. Wonderful!



A pair of Nickel Metal Hydride rechargeable AA cells was tested for impedance. They were connected to the C60 via a 1000µF low Z capacitor. This stops any DC current from entering the C60 and overheating it. The lower (black) plot is the impedance of the capacitor on its own. It claims to have an ESR of 70mR at 100KHz. The plot indicates 90mR, but also includes the screw terminal adaptor, the C60 output inductance and the wire leads of the capacitor. This plot shows the errors caused by the capacitor coupling. The impedance increases at low frequencies because of the capacitor and increases at high frequencies because of the stray inductance of the test fixture.

The middle plot (red) is a freshly recharged pair of batteries. At 10KHz, the internal impedance is 0.4R. A 1 Amp current surge will cause the voltage to dip by 400mV. The top plot (blue) is a pair of the same type of batteries that had powered a digital camera for 50 shots. The internal impedance at 10KHz is 3.5R. A 1 Amp current surge will cause the voltage to dip by 3.5V. Testing the battery impedance is another tool that can be used to monitor battery quality.

Characteristic impedance – Cables

Put two or more insulated conductors together in a long cable and a characteristic impedance is formed between them. This is because they virtually occupy the same physical space and so have mutual capacitance and inductance.

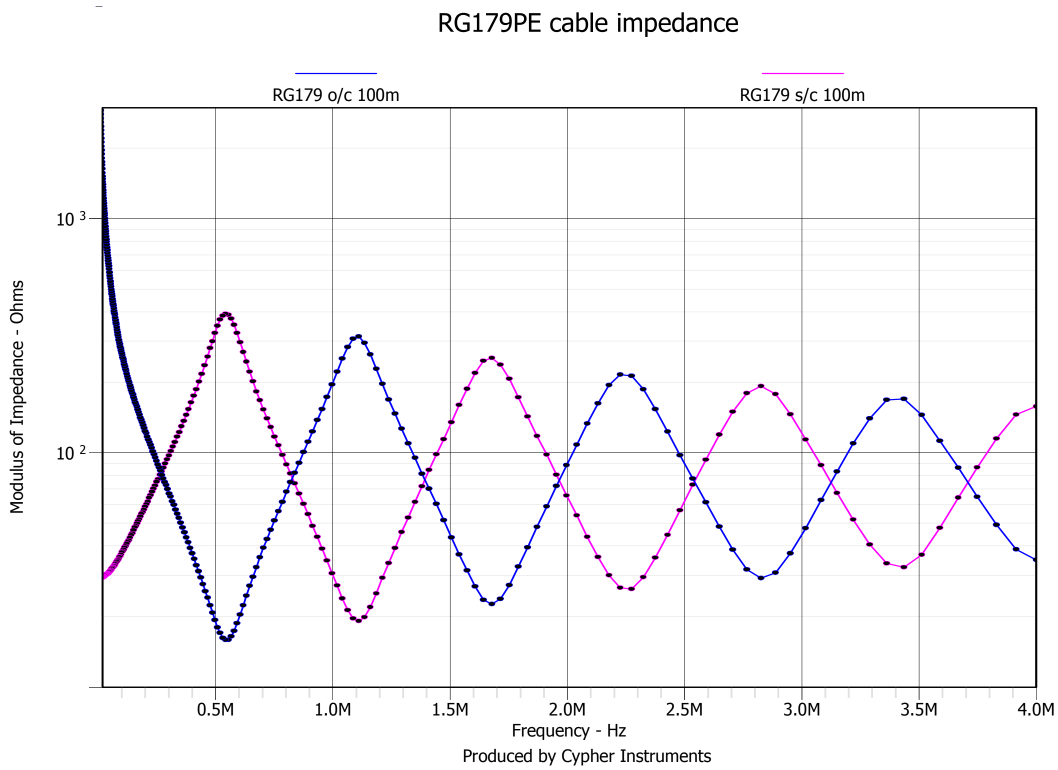
This impedance is defined by; $Zc = \sqrt{L/C}$, where Zc is the characteristic impedance of the cable and L & C are the lumped inductance and capacitance per unit length of the cable. As we don't have values for either of these, the formula is only useful to cable designers who have control over the physics of the design. There are two methods of finding out the characteristic impedance of a cable. One; it is written on the cable drum and sometimes on the cable. Two; if that is too easy for you, then you can measure it.

Method

Take the cable and strip the insulation at both ends. Connect one end of the cable (two wires) to the C60. Measure the impedance with the far end of the cable open circuit and then repeat with a short circuit. A reel of less than 100 meters of RG179PE was tested (below). The open circuit Z (blue) is large at low frequencies; the short circuit Z (mauve) is equal to the DC resistance of the cable loop.

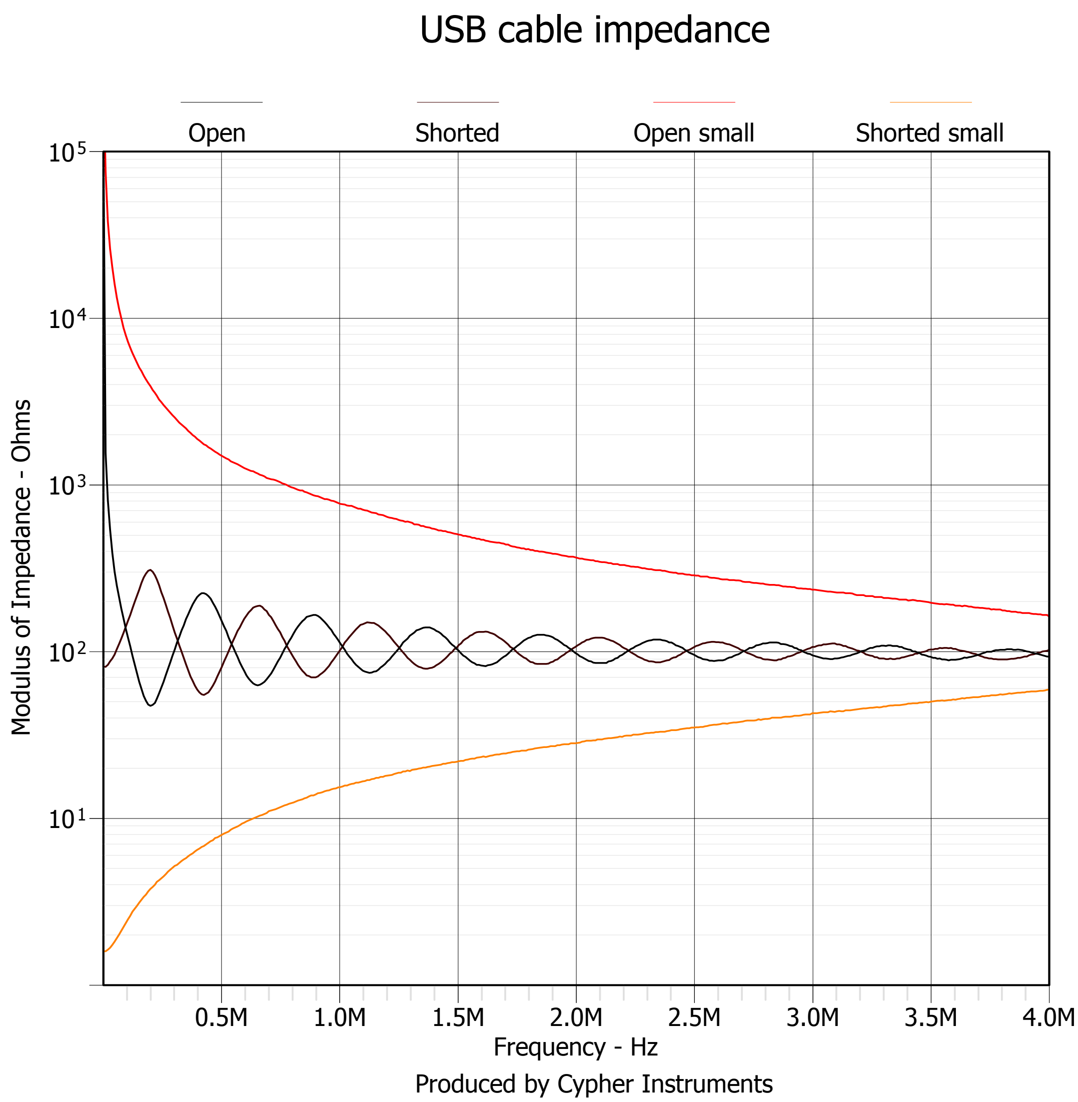
The cable impedance at high frequencies is defined as; $|Zc| = \sqrt{|Zopen| \times |Zshort|}$.

Using the graph below; at high frequency, take a value for the open and shorted impedance, multiply and square root to obtain a value for the characteristic impedance. At three increasing frequencies, values of 75.4R, 74.2R and 73.9R were calculated. The RG179PE is specified at 75R ± 3R. The characteristic impedance can be obtained without mathematics; it is the value at the intersection of these two plots.



Note that the graph uses a linear Frequency axis. The cable is about 100 meters long and time domain effects can be seen (the wave length in the cable). The RG179PE is a small diameter, general purpose screened coaxial cable. The screen and the inner conductor form the characteristic impedance.

The next cable to be tested has been designed to connect USB-1 devices together. USB-1 uses data rates of 12 Mbits per second. It is important that the data wires in this cable bundle have a well specified characteristic impedance. Electronic transmitters differentially drive the cable with a known drive resistance and the receivers also have a known termination resistance. In this way, data waveform shapes are well preserved, leading to minimal data errors. The USB cable bundle has two data wires that are twisted together, a pair of power wires that are not twisted and an overall screen. The cable was designed to send and receive data, to power peripheral devices and to be flexible by virtue of using multi-strand conductors (unlike most Ethernet plumbing). The graph shows the impedance plots of the data pair for a 200m reel of cable (black and brown) and a 4m length (red and orange). The screen and power wires were left floating for this test. The USB standard says that the cable length shall not exceed 5m because of transmitter and wavelength limitations.

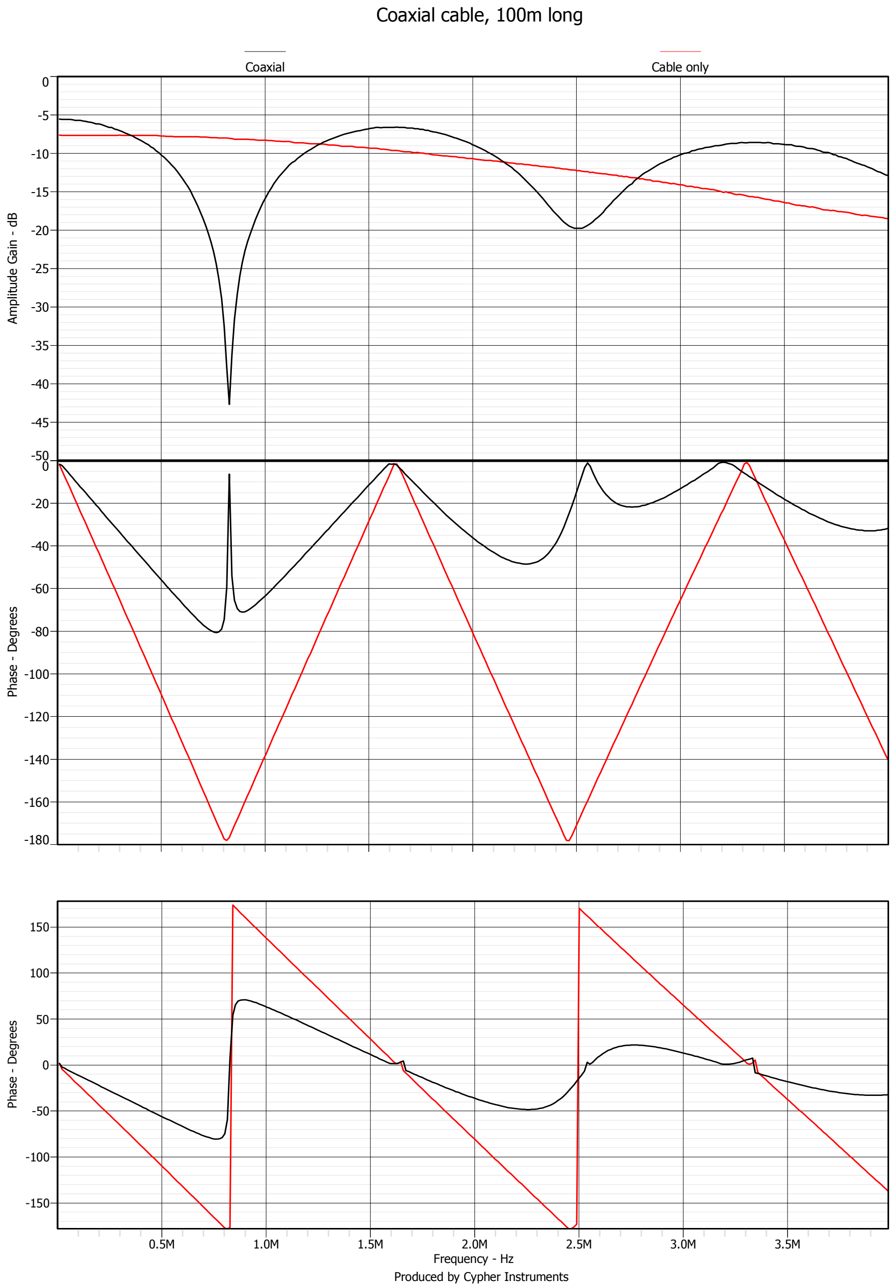


Again, a linear frequency axis reveals the regular time domain variations in the 200m cable. It looks like all four plots are aiming for the same final value. At any frequency, take a value for the open and shorted impedance, multiply and square root to obtain a value for the characteristic impedance. This gives values of 102R to 97.2R for the 200m length, and 95R for the 4m length. The USB specification for cable impedance is 90R ± 15%.

Measuring delay times – Cables

The signal propagation delay time of a 100m drum of coaxial cable was tested (below). One end of the cable was driven via an external amplifier. The far end of the cable was resistively terminated by 75R. The output of the C60 and the far end of the cable were resistively mixed together and fed into the input of the C60. The resultant linear frequency response shows a cosine comb filter response (black). This is caused by the differential time delay of the two signal paths. The red plot shows the cable on its own. It has high frequency losses that cause the notch depth to diminish with frequency. The first notch is at 828KHz. This is when the time delay is half a wavelength. A sine wave of 828KHz has a wave length of about 1.2µS, so half a wavelength is 600nS. That means that the signal took 600nS to travel the 100m cable length. Therefore, the velocity down the cable is given by V=D/T, which is V=100m/600nS. This is 166km/S, which is slower than the velocity of light at 300km/S. For a cosine comb response, further notches occur at 3F, 5F, etc.

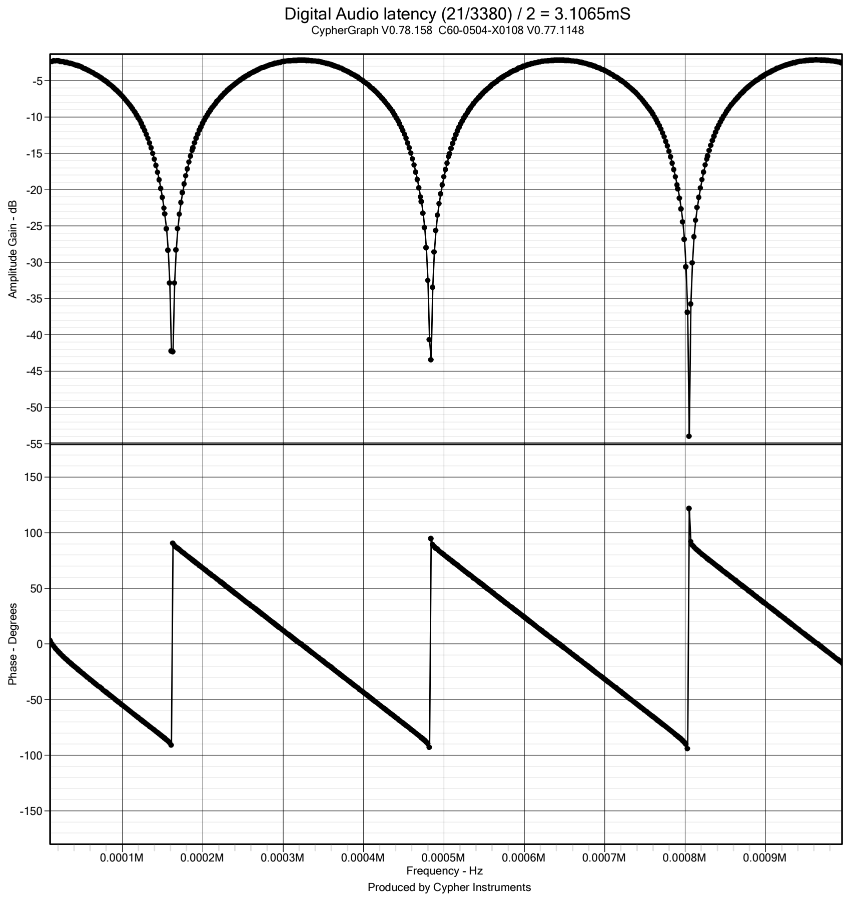
Both phase responses are shown on one graph by using a cut and paste process. The middle plot (red) shows a triangle response. This is the phase response of a constant time delay. When this response is unwrapped to show ±180^{0} (lower plot), the response is a ramp waveform. Phase errors are now more visible at the zero crossing and at the extremes. Note, the data was acquired with the Linear mode selected, so the points are linearly spaced.



Digital audio devices

A digital audio device was driven by the C60. The signal was converted by an ADC into a 24 bit digital data stream and then reconverted back into an analogue signal with a DAC. This loop back test reveals some of the perils of high quality digital audio systems. Both conversion processes send the data through long transversal digital filters that shape the signal and noise spectrums and also recovery the analogue signal. This filtering takes time to process the signals, in this case 3.1 milliseconds. The input signal was resistively mixed with the non-inverted delayed signal. If the two signals have the same amplitude, then a cosine comb response is produced. At 161Hz on the graph, the first notch appears. A frequency of 161Hz has a period of 6.2mS. However, a delay of half of 6.2mS will produce a delayed sine wave output that is in anti phase with the input signal. When these two signals are added together they cancel each other out, producing a notch in the frequency response. So, the delay time of the unit is 6.2/2 = 3.1mSec.

The notches repeat every 322Hz. There are 62 of them going all the way up 20KHz. This is a nightmare for the audio industry. Imagine sending a signal off to a digital effects unit, and then mixing it back in with the source signal. Often, the resultant mix will have a 'drain pipe' quality to it, caused by the inadvertent comb filtering.



The phase response is the classic saw tooth shape. At 0Hz, the input and output are in phase with each other, and so the phase shift is zero. As the frequency increases, the phase swings linearly towards -90^o, and then flips around by 180^o (at the zero) and continues to ramp downwards. The phase detector and the sign detector are operating in near ideal conditions. The signals are low frequency (20KHz max) and large (2Vpp). Compare this with a 2MHz sine wave at -60dB. The frequency is 100 times faster and the signal is 1/1000th of the level.

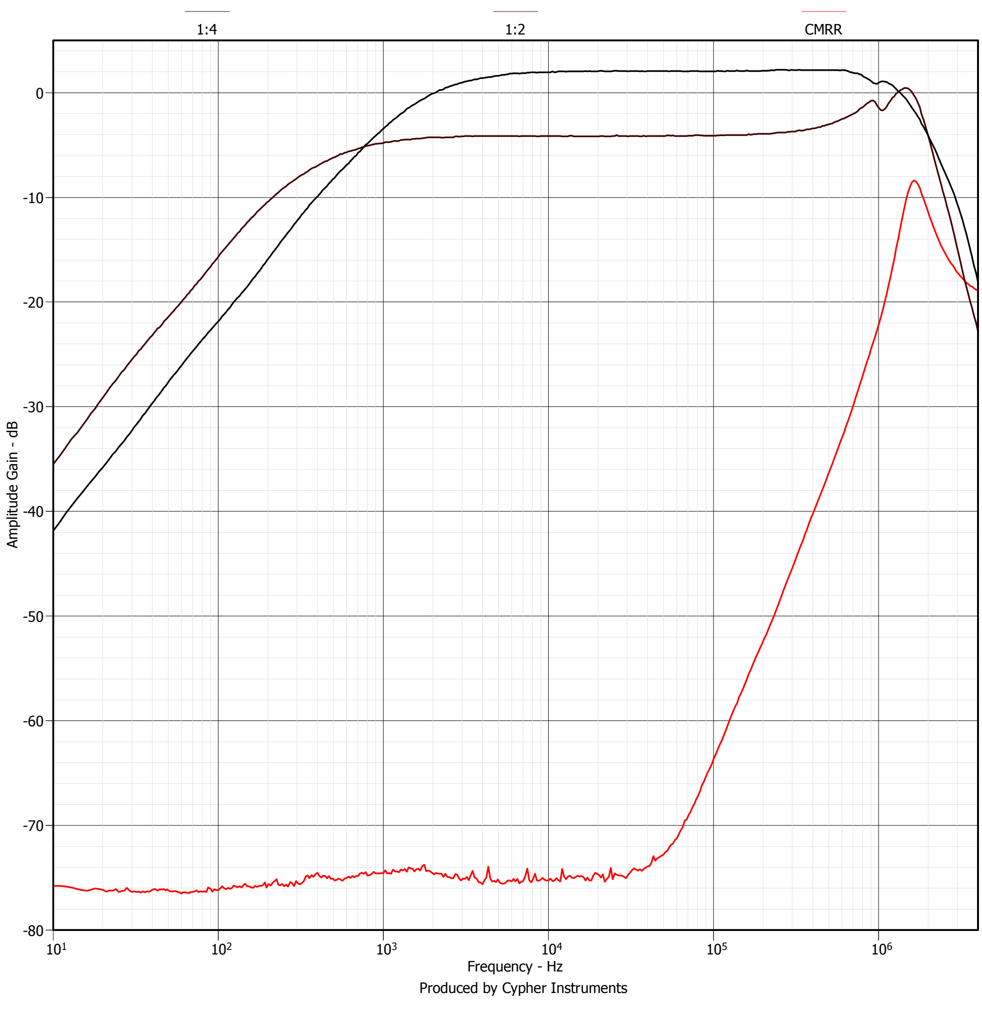
Transformer – Transmission

Isolation transformers are often used to couple signals from one part of a circuit to another. There is no conducting electrical connection from one side to the other, which is useful when galvanic isolation is needed to provide an electrical safety barrier. Barrier voltages of several thousand volts are easily obtained with slit bobbins or tape layers. Transformers can be used to provide balanced inputs or outputs, which are sometimes referred to as 'floating' or 'differential connections'. These transformers pass differential signals, but block common mode signals, which tend to be interfering signals. To be well balanced, a transformer would need to be symmetrically constructed, which is physically difficult. Signals are magnetically coupled from the input windings to the output windings. If the input/output winding ratio is less than unity, then the transformer will provide a voltage gain. The transformer seems to be an engineering miracle, but does it have any drawbacks?

The amplitude response of a transformer with a 1:2 and 1:4 ratio was tested (below). The transformer has a 'band pass' response. It has a high pass section, a flat pass band that extends for about two decades and then a sharp cut off. This is a typical transformer response. It is very difficult to make a transformer with a wide frequency response and a flat pass band. This part was designed to operate from 40KHz to 120KHz which is the relatively flat part of the response. The plots show the amplitude gains of +6dB and +12dBs (less a 10dB output attenuation from the C60).

The common mode rejection ratio [CMRR] was also tested (red plot). All the input terminals were connected together and driven by the C60's output. The signal at the output shows a dramatic rise in amplitude, which suggests that this transformer has a poor CMRR at high frequencies. There is no copper screen between the windings in this transformer design. If there had been an earthed screen, then the CMRR would have been greatly improved.

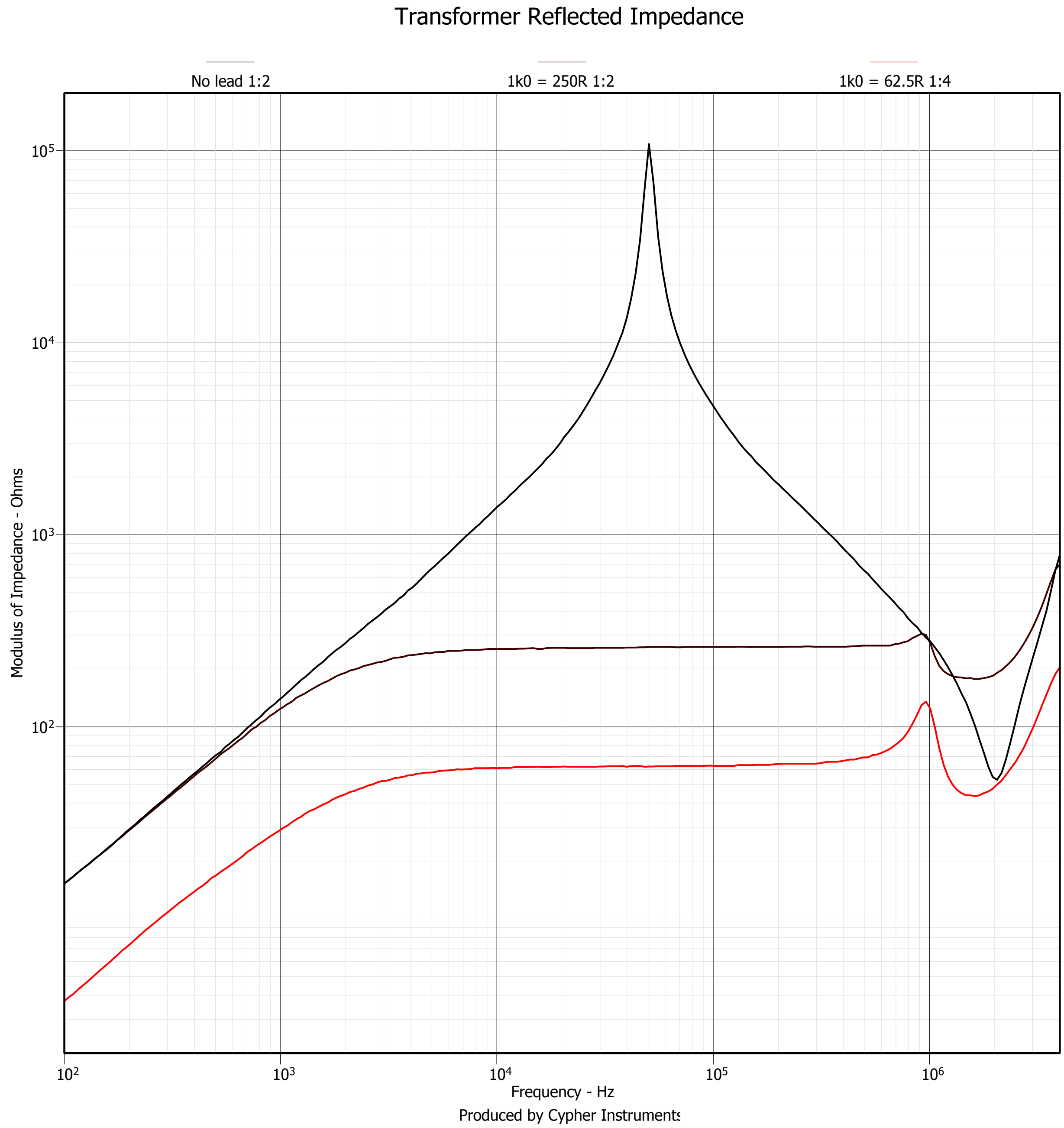
Transformer with 1:2 and 1:4 ratios. Output attenuation = -10dB.



Transformer – Reflected Impedance

A transformer can be used to provide a voltage gain. The transformer in the test below has two winding ratios of 1:2 and 1:4. If it is driven with a 1Vpp signal, then 2Vpp and 4Vpp can be obtained at the output. It is a passive voltage amplifier, with no power gain. The input side of the transformer 'sees' the load on the output through the transformer windings. If the output voltage across the load has doubled, then the output current into the load will double. The load impedance 'seen' at the input has increased with the square of the turns ratio. The word 'load' can be misleading. If the load was resistive, then increasing the load is to reduce the resistance. So, if you drive a resistor through a transformer with a voltage gain (N), the resistance 'seen' at the driving side is reduced by N^2. The voltage gain (N) is also the turns ration. For N=2, the load quadruples. For N=4, the load increases by a factor of sixteen. This is also true for reactive loads such as capacitors and inductors.

The input impedance of the transformer was examined. With the outputs open circuited, the transformer shows a very peaky self resonance. With a 1K0 resistor across the X2 output, the load is 1K0/4 = 250R. With a 1K0 resistor across the X4 output, the load is 1K0/16 = 62.5R. If the transformer had a X10 output, the load would be 1K0/100 = 10R.



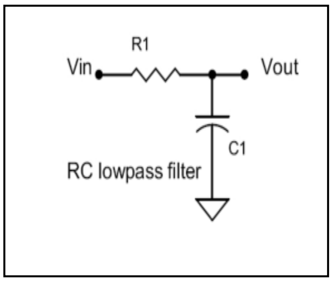
Appendix A

Amplitude responses and phase shifts in simple electrical circuits

There is not total agreement on the definition of phase shift in books, filter programs and web sites. Many sources get the phase sign, filter equations and graphical response wrong! This appendix should help resolve the confusion.

A first order RC low pass filter has a steady state phase lag when driven by a sine wave. This phase lag is represented by a negative phase value. At low frequencies, the input and output signals are almost in phase, approaching 90^o at high frequencies. The amplitude and phase equations for a first order RC low pass filter are shown below. With component values of R1=1 and C1=1, the filter has break frequency (-3dB point) of 1 radian per second.

First order low pass response



The amplitude response, Vout/Vin is referred to as A.

$$\mathrm{A} = \frac{1}{\sqrt{1+\omega^2}}$$, where ω is the test frequency.

This can be expressed in dBs of loss.

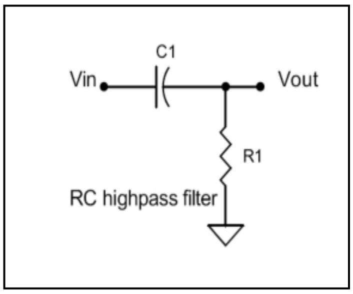
$$\mathrm{A}_{dB} = 20.\log_{10}\left(\frac{1}{\sqrt{1+\omega^2}}\right) \text{dB}$$

The phase shift measured from Vin to Vout is referred to as ϕ.

$\phi = -\tan^{-1}\omega$, where $\tan^{-1}$ indicates the arctan function.

A first order RC high pass filter has a steady state phase lead when driven by a sine wave. This phase lead is represented by a positive phase value. This lead is actually an extra long lag. Time travel has not happened! At high frequencies, the input and output signals are almost in phase, approaching 90^o at low frequencies. The amplitude and phase equations for a first order RC high pass filter are shown below. The filter has break frequency (-3dB point) of 1 radian per second (1/[R1C1]).

First order high pass response



The amplitude response, Vout/Vin is referred to as A.

$$\mathrm{A} = \frac{\omega}{\sqrt{1+\omega^2}}$$, where ω is the test frequency.

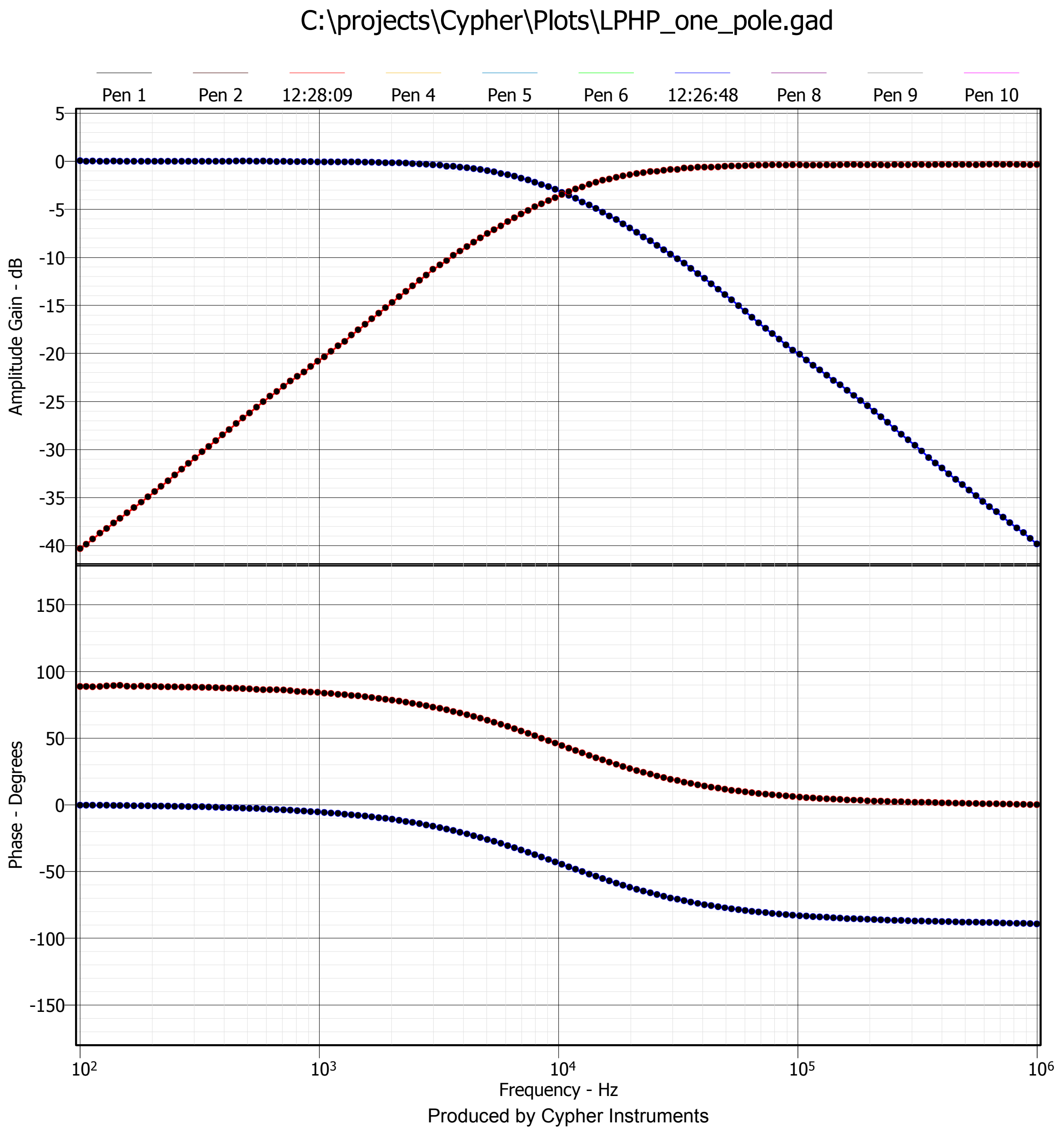
This can be expressed in dBs of loss.

$$\mathrm{A}_{dB} = 20.\log_{10}\left(\frac{\omega}{\sqrt{1+\omega^2}}\right) \text{dB}$$

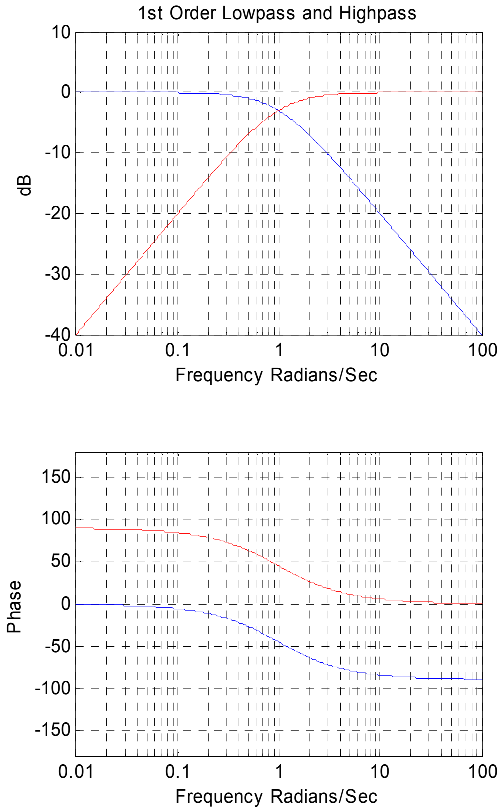
The phase shift measured from Vin to Vout is referred to as ϕ.

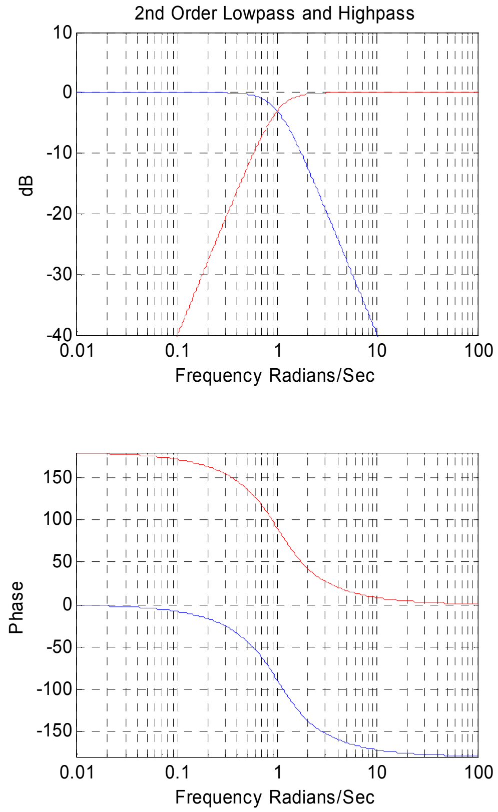
$\phi = +\tan^{-1}\frac{1}{\omega}$, where $\tan^{-1}$ indicates the arctan function.

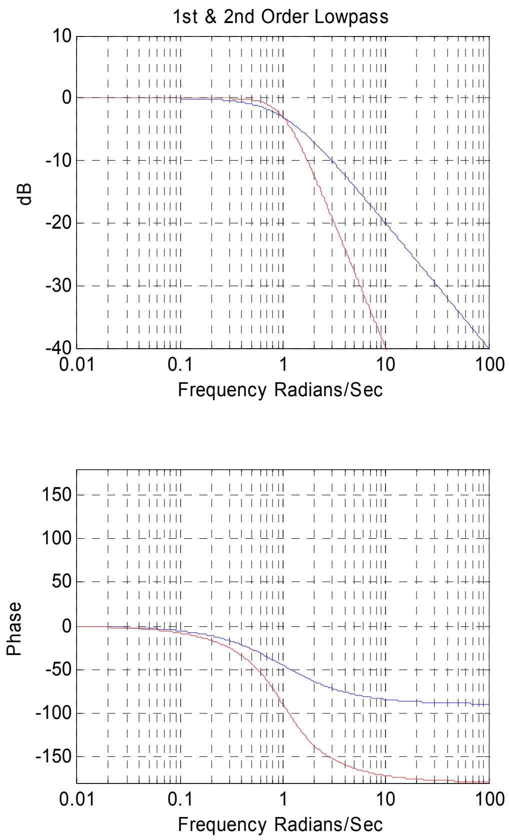
The top section of the graph is the measured amplitude response of a single pole (first order) high pass filter (red) and a single pole low pass filter (blue). The bottom graph is the phase response of the high pass filter and the low pass filter.

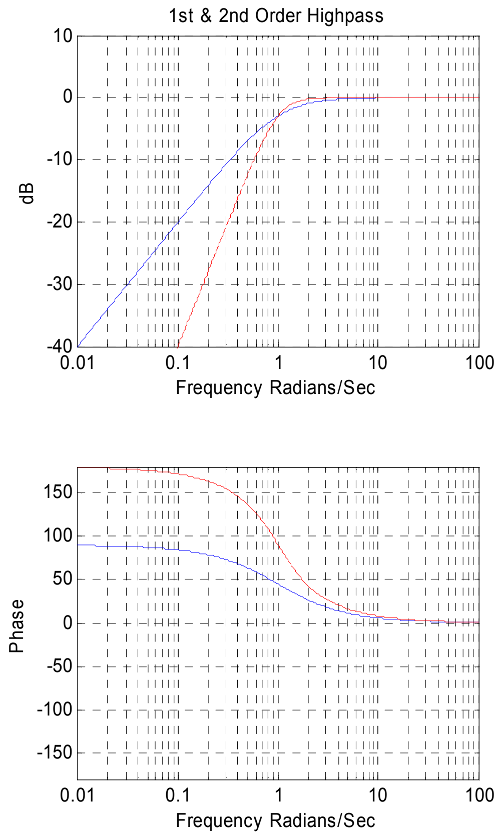


On the next page are the calculated responses of first and second order high and low pass filters. Butterworth designs were used for this simulation. The Butterworth filter is called maximally flat because it has no overshoot in the 'Amplitude' frequency response. Other filter designs trade pass band flatness for stop band attenuation. These show up in the phase response, group delay and step response. For best wave shape preservation, use a Bessel filter. This has a 'flat' group delay, but poor roll off response. The Butterworth filter has a better initial roll off slope at the expense of over shoot to a step drive. The poles of a high order Butterworth filter are all at the same frequency, only the Q factors are different. For faster roll off slopes, Chebyshev filters trade pass band ripple, wild phase responses and time domain ringing for rapid initial roll off slopes. Even faster roll offs can be obtained with Cauer or Elliptic filters. These use stop band zeros that cause the output signal to disappear into notches that are situated along the frequency axis. A signal passing through a zero suffers an instantaneous 180° phase shift. However, the signal has zero amplitude and so that makes it an event that is difficult to observe.

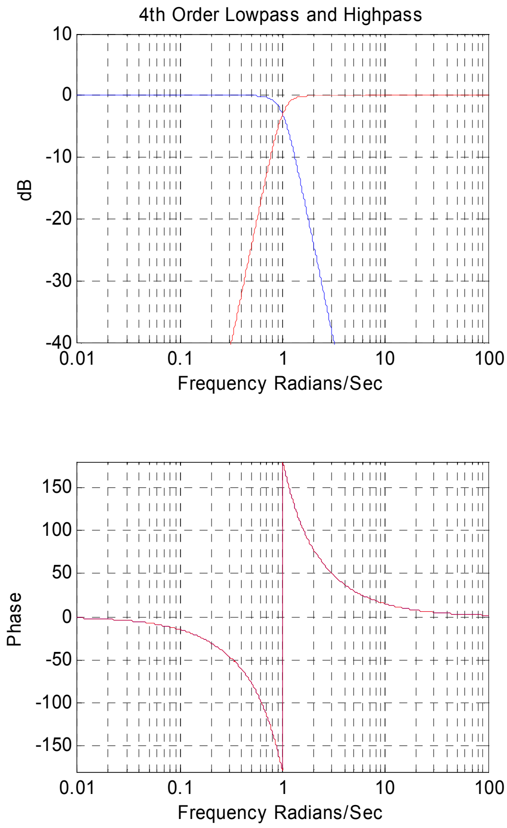

1st Order Lowpass and Highpass
dB
10
0
-10
-20
-30
-40
0.01
0.1
1
10
100
Frequency Radians/Sec
Phase
150
100
50
0
-50
-100
-150
0.01
0.1
1
10
100
Frequency Radians/Sec


2nd Order Lowpass and Highpass
dB
10
0
-10
-20
-30
-40
0.01
0.1
1
10
100
Frequency Radians/Sec
Phase
150
100
50
0
-50
-100
-150
0.01
0.1
1
10
100
Frequency Radians/Sec

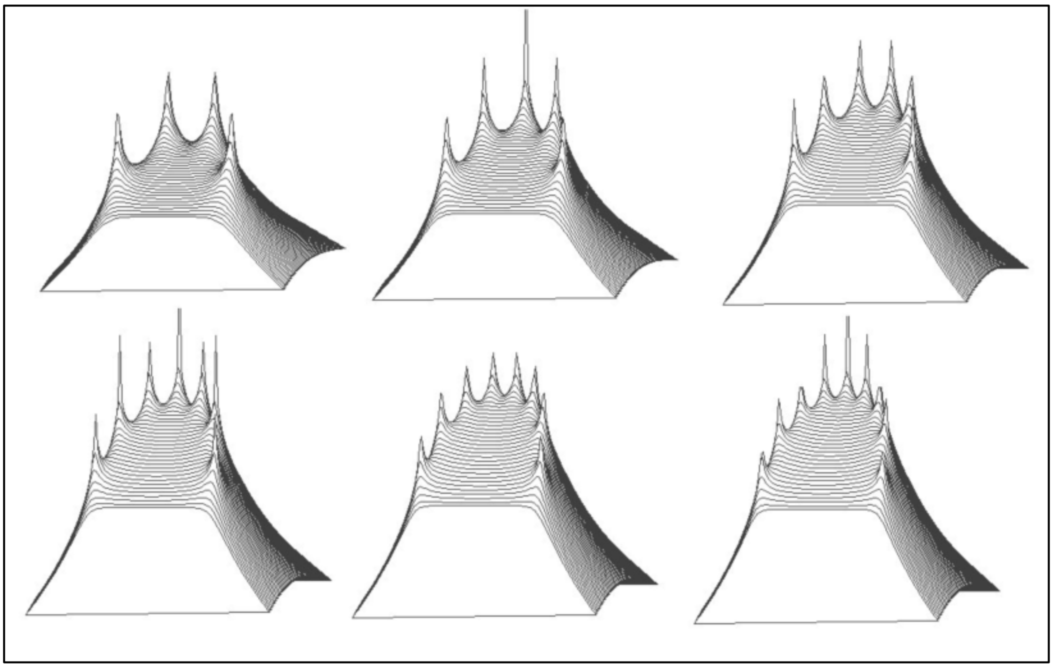

1st & 2nd Order Lowpass
dB
10
0
-10
-20
-30
-40
0.01
0.1
1
10
100
Frequency Radians/Sec
Phase
150
100
50
0
-50
-100
-150
0.01
0.1
1
10
100
Frequency Radians/Sec


1st & 2nd Order Highpass
dB
10
0
-10
-20
-30
-40
0.01
0.1
1
10
100
Frequency Radians/Sec
Phase
150
100
50
0
-50
-100
-150
0.01
0.1
1
10
100
Frequency Radians/Sec

Another simulation shows a fourth order Butterworth low pass and high pass filter. The filter slopes are 24dB/octave or 80dB/decade. The phase excursions are 360° in magnitude. When the two steady state phase responses are plotted on the same graph they are coincident. Actually, they are always 360° apart, but this type of graph wraps the phase data and so they appear to be coincident.



S plane pictures by courtesy of James Grant



Above, is a range of low pass Butterworth filter responses, drawn above the S plane. These are all pole devices, with filter orders from 4 to 9. The Butterworth design is maximally flat in the frequency domain. However, their response to a step function will produce an overshoot. The poles are evenly spread on a semicircle whose origin is the axis crossing of the S plane. The 3D plots are vertically sliced along the $j\omega$ (imaginary) axis to reveal amplitude response.

Appendix B

Reactance and Impedance in simple electrical circuits

The Reactance of physical object is a description of how it resists the flow of current when driven with a sinusoidal voltage. As the frequency varies, the magnitude of the Reactance varies. For electronic components there are three types of Reactance. These are referred to as $X_{L,}$ $X_{C,}$ and $X_{R,}$ which are respectively the reactance of *pure* inductive, capacitive and resistive devices. Reactance is expressed in the units of resistance, the Ohm. Inductors have the property of storing magnetic energy by way of moving electrons (current). Capacitors store electric energy in the form of a static collection of electrons (charge). Resistors store absolutely nothing. They waste electrical energy by turning it into heat.

Definition of the Reactance of *pure* inductance, capacitance and resistance

$X_L = 2\pi f L$,where f is the frequency in Hz and L is inductance in Henrys

$X_C = 1/(2\pi fC)$,where C is the capacitance in Farads

$X_R = R$,where R is resistance in Ohms

The inductor has a Reactance that is proportional to frequency. Double the frequency and the Reactance will double in magnitude. Graphically, this is slope that rises in magnitude by +6dBs for every octave increase in frequency (see plot below).

The capacitor has a Reactance that is inversely proportional to frequency. Graphically, this is slope that falls in magnitude by -6dBs for every octave increase in frequency.

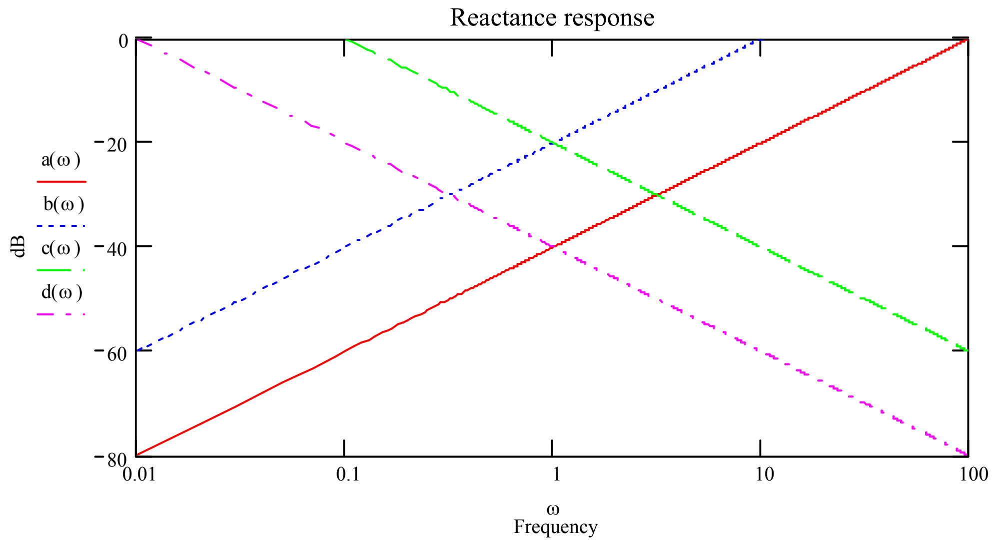
The resistor is not frequency dependant. Its Reactance has a constant value.

The Reactance of two inductors and two capacitors plotted as a function of frequency

$\omega := 0.01, 0.02..\ 100$ $L := 0.01$ $C := 1$

Inductors $a(\omega) := 20\log(\omega \cdot L)$ $b(\omega) := 20\log(\omega \cdot L \cdot 10)$

Capacitors $c(\omega) := 20\log\left(\frac{1}{\omega \cdot C \cdot 10}\right)$ $d(\omega) := 20\log\left(\frac{1}{\omega \cdot C \cdot 100}\right)$



Reactance is used to describe *pure* inductance and capacitance. A mixture of LCR components is said to have a Complex Impedance. Real components contain all three types of Reactance in the form of stray capacitance, stray inductance and series/parallel resistance, all of which compromises their functionality.

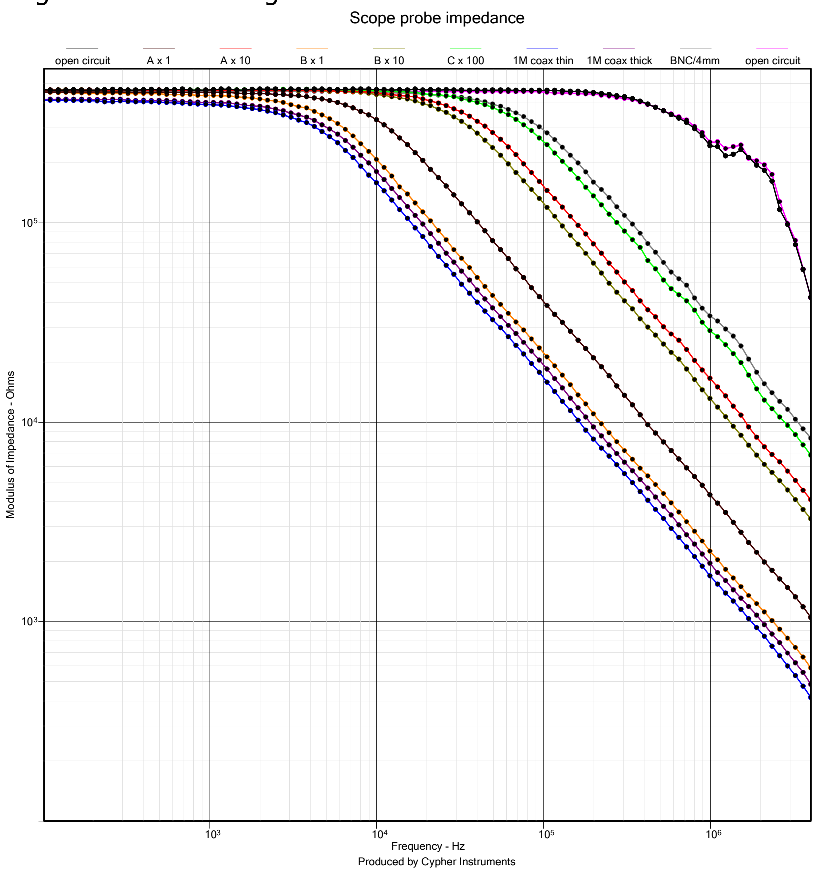
In fact, many components can self resonate, inductors and capacitors being common examples. Manufacturers often provide a SRF value (self resonant frequency) for inductors. At this frequency the inductor and its stray capacitance form an LCR resonator. Above this frequency the device behaves more like a capacitor. Conversely, the leads on a capacitor are inductive. These form series LCR resonators that makes the device behave as an inductor past the resonance frequency. Impedance plots from component manufacturers are often to use to illustrate this behaviour.

Wires and printed circuit board tracks introduce stray inductance and capacitance to electronic networks. One inch of wire can have an inductance of about 20nH (*rule of thumb*). This has a Reactance of 1.25 ohms at 10MHz. If a peak to peak sinusoidal current of 2Amps is flowing through this wire, then there is a 2.5Vpp voltage drop across the one inch of wire. This voltage is produced by the Reactance of the wire. My personal record was 22Vpp sustained across a lead from a BNC connector to ground in a prototype RF power amplifier.

A 1X scope probe has an input resistance of 1Mohm and an input capacitance of about 100pF. Past 1.59kHz, the probe Impedance is dominated by the capacitor. At 1MHz, the 1Mohm scope probe has an Impedance of 1591 ohms, and at 10MHz, it is 159 ohms. Often a circuit will change its operation when a scope probe is connected. Why could that be? A FET scope probe with a 1pF//1MR input capacitance will reduce this problem. The down side is that a FET probe can cost as much as the scope. Another scope probe Impedance phenomena is the earth clip. This forms a nice loop inductor, which can resonate with the probe capacitance. This self resonance limits the bandwidth of the probe. This effect can be seen by probing a high speed logic signal and then curling the earth lead around the probe body. The signal seen on the scope has resonant edges that can be changed by modifying the earth clip geometry. The inductance can be minimized by using a probe with a tip and pointed earth ring. For this to work, the part of the circuit being probed needs a local earth pad. This is almost impossible to arrange. Most circuits are constructed from very small surface mount components. A 0.4mm IC pin pitch is not uncommon! The problem with probing these boards is one of physical size, quite apart from the probe impedance. Scope probes have not reduced much in size in the last 40 years and now are often as big as the board being tested!

A selection of scope probes and other connectors was tested (right). The highest impedance probe was a X100 device (green). The worst probe was the 'B x 1' (orange), which was 584 Ohms at 4MHz. This graph shows how much loading a scope probe will present to a circuit, even at relatively low frequencies. Two coaxial BNC to BNC leads were also tested (blue & mauve). They presented the biggest loading.

The BNC to 4mm adaptor (grey) was a surprise. It has an impedance of 34K at 1MHz, which is equivalent to a 4.5pF capacitor. Even this small capacitance shows up on the graph.



Appendix C

The scripting language

Test scripts are ASCII text files that contain instructions to control the instrument to perform a test or set of tests. This enables the user to run a collection of tests and leave the program to it, rather than having to control the program manually. This is most useful if you wish to perform production testing or quality control tests on a large quantity of devices. The test script can be written using any non-document text editor (such as notepad.exe) and are downloaded to the instrument where it resides in non-volatile memory. This allows an instrument to be configured to test a particular device.

The instrument can also control an external multiplexer to switch between different parts or channels of a device that require testing. The test script language (known as CypherScript) allows full control of the instrument as well as the ability to save the graphs and export the data in any of the supported formats. A test script can be passed to CypherGraph via the command line, or re-run the test script in non-volatile memory (with –rerun), allowing test automation of the instrument and the CypherGraph software. For example below is a small example of a test script. A "#" or hash character at the start of a line defines a comment. For reading ease the comment are in green, the commands in blue and the data is in black text.

```
# Load a new amplitude document and name it "My Graph"
newampf My Graph
# Set the number of points
points 500
# Start the test from 1K to 100KHz
amptest 1000 100000
# Label the line
legend My Device
# Wait for the test to complete
wait
# Set the export format not to append time, date and serial number
# and use a precision of 3 decimal places
exportformat 1 0 0 0 3
# Export the data in plain ASCII text
exporttxt Pen1TextFileName
# Save the graph to the hard disk in the plot files folder with time, date and serial no.
exportformat 0
savegraph My Graph
# print the graph (0 = portrait 1 = landscape)
printgraph 0
# close the graph
close
# End of file
```

If the hash character is omitted the first word will be parsed as a command and it is likely that an error will occur as most will either be invalid commands or pass invalid data. The first command 'newampf' will open a new amplitude verses frequency graph and title it 'My Graph'. The second command, 'points' sets the number of test points to 500. The third command is 'amptest' this command starts the test from 1K to 100KHz. The next command is 'legend'; this command sets the pen legend text to "My Device". The command 'wait' halts script processing until the test has completed. Otherwise the test script will execute the command before the test has finished. The 'exportformat' command defines the text format with which to output the data, and the exporttxt command writes the file to the hard disk in the export folder. The next command is 'savegraph' this command saves and closes the graph. The text following the command is the name given to the file when it is saved. The name given to the saved file also contains the date and time of the save, this is because the 'exportformat 0' command specifies this behaviour. The 'printgraph' command then prints the graph to the default printer in portrait orientation. Finally the 'close' command closes the document.

Scripts commands are executed one after another in the order they appear in the text file. There are no facilities to loop or jump. Strings and file names can be of a maximum of 62 characters in length. Script files can be a maximum of 25K bytes (25600 characters). Windows file name character restrictions do not allow the following characters; /,\,:,*,",<,> and |. If any of these characters appear in a file name they will be removed. If a file name or title is omitted the user will be prompted to enter one.

Script commands

There are a total of 35 commands used to control the instrument, which are outlined Figure 1. Each command has none, one or more parameters and a return character to signify the end of the command.

Command	Description
abort	Aborts the test script
amptestt	Starts an amplitude test
atten	Sets the output attenuator in 2.5dB steps
close	Closes the current open document
checkmask	Checks the specified pen's data set against the masks for a GO or NO GO result
endfreq	Specifies the end frequency of the sweep in Hz
exportbmp	Exports a bitmap image file of the graph to the Exports folder
exportjpg	Exports a JPEG image file of the graph to the Exports folder
exporttxt	Exports an ASCII text file of one pen's data
exportformat	Specifies the export file format for ASCII text and file naming
exportwmf	Exports a Windows meta file image of the graph to the Exports folder
idlefreq	Specifies the oscillator frequency when not testing
imptest	Starts an impedance test
legend	Adds text to a pen legend
linear	Specifies linear or logarithmic test points
loadgraph	Loads a graph from the Plots folder
message	Launches a dialog box with text to inform the operator
newampf	Opens a new amplitude Vs Frequency graph
newimpf	Opens a new modulus of impedance Vs Frequency graph
period	Specifies the time period in milliseconds between test points
phase	Enables / disables phase data acquisition
points	Specifies the number of test points to take
printgraph	Prints the graph
prompt	Launches a dialog and waits for the user to click OK
promptabort	Launches a dialog and aborts script processing if the Yes button is clicked
prompnottabort	Launches a dialog and aborts script processing if the No button is clicked
quit	Quits the CypherGraph application
savegraph	Saves the graph
setpen	Sets the pen number to use
setpin	Sets the output control pins
sleep	Halts script processing for a specified number of milliseconds
startfreq	Specifies the start frequency of the sweep in Hz
sweepmode	Specifies the direction of sweep
title	Adds text to a graph's title
wait	Halts script processing until the test has completed

Figure 1 Table of test script commands

The alphabetical list of commands below includes a description of each one with an example. All commands must be in lower case letters.

A

abort

abort<CR>

This command aborts further processing of a script.

Example:

```
# Save the graph
savegraph X303
# export a wmf
exportwmf X303
# print the graph (0 = portrait 1 = landscape)
printgraph 0
# for now leave the file open for examination
abort
# close the graph - because the abort command is executed before the close
# script processing is stopped before the document is closed
close
```

amptest

amptest startFrequency endFrequency numTestPoints<CR>

startFrequency – Optional parameter to specify the starting frequency (A) in Hz
endFrequency – Optional parameter to specify the ending frequency (B) in Hz
numTestPoints – Optional parameter to specify the number of test points to use

This is a command to start an amplitude test. Three optional parameters can be passed to the command these are start frequency (A), end frequency (B) and number of points. The test is then started. If the command is passed without additional parameters the settings are as previously set or default if not specified by another command. Before this command is executed a document should be opened with newampf, newimpf or loadgraph command. It should also be followed by the wait command to halt further script processing until the test has finished.

Example:

```
# Load a new amplitude document and name it "My Graph"
newampf My Graph
# Set the number of points
points 500
# Start the test from 1K to 100KHz
amptest 1000 100000
wait
```

atten

atten attenuationCode<CR>
attenuationCode – Parameter to specify the output attenuation in 2.5dB steps

This command specifies the oscillator output attenuation according to the table in Figure 2.

Attenuation Code	Oscillator output attenuation in dB
0	0
1	2.5
2	5
3	7.5
4	10
5	12.5
6	15
7	17.5
8	20

Figure 2 Oscillator output attenuation codes

Example:

```
# Load a new amplitude document and name it "My Graph"
newampf My Graph
atten 0
linear 0
sweepmode 0
imptest 1000 3000
legend 0dB
wait
atten 1
imptest
legend -2.5dB
wait
```

C

close

close<CR>

A command to close an open document. It isn't necessary to pass any parameters with the command. It is recommended that only one document is open at any one time. This will avoid confusion over which is the active document in CypherGraph's Multi-Document user interface. Therefore when the data has been acquired and saved or exported to the hard disk then the document should be closed before a new one is opened.

Example:

```
newampf Amplitude
prompt A new amplitude document
close
newimpf Impedance
prompt A new impedance document
close
```

checkmask

checkmask penIndex passNotification failNotification abortScriptOption<CR>

penIndex – The index of the pen (0 to 9) to compare against the mask

passNotification – Launch a dialog box to notify of pass when set to 1. No notification when set to 0.

failNotification – Launch a dialog box to notify of failure when set to 1, No notification when set to 0.

abortScriptOption – Option to abort script processing when set to 1 on failure, 2 for pass and no abort when set to 0

When data has been acquired into a graph with limit masks drawn, CypherGraph can compare the data against the masks to produce a "PASS" or "FAIL" result. The check mask command allows this to be automated. The pen index, pass notification, fail notification and abort script processing parameters define the actions of the command.

Example:

```
# Check the data (pen 3 - index 2) against the mask
# Do not inform on pass, inform on fail, abort test script on fail
checkmask 2 0 1 1
```

E

endfreq

endfreq endFrequency<CR>

endFrequency – Parameter to specify the end frequency (B) in Hz

Example:

```
endfreq 4000000
startfreq 10
```

exportbmp

exportbmp bmpFileName<CR>

bmpFileName – Optional file name of the bitmap file without the file extension (.bmp)

This command exports a bitmap image of the graph to the export folder using the file name specified. If the file name is omitted then the user is prompted to enter one. If no file name is entered then the file is not saved. File paths are not allowed, only the file name. Windows file name character restrictions apply.

exportjpg

exportjpg jpgFileName<CR>

jpgFileName – Optional file name of the JPEG file without the file extension (.jpg)

This command exports a JPEG image of the graph to the export folder using the file name specified. If the file name is omitted then the user is prompted to enter one. If no file name is entered then the file is not saved. File paths are not allowed, only the file name. Windows file name character restrictions apply.

Example:

```
exportformat 1
exportbmp BmpFileName
message Done!
# eof
```

exporttxt

exporttxt txtFileName<CR>

txtFileName – Optional file name of the text file without the file extension (.txt)

This command exports one pen's data as ASCII text to the export folder using the file name specified. If the file name is omitted then the user is prompted to enter one. If no file name is entered then the file is not saved. File paths are not allowed, only the file name. Windows file name character restrictions apply. The pen to export should be specified by the exportformat command.

Example:

```
exportformat 1 0 0 0 3
exporttxt Pen1TextFileName
exportformat 1 1 1 0 3
exporttxt Pen2TextFileName
exportformat 1 2 1 1 3
exporttxt Pen3TextFileName
exportformat 1 3 0 0 3
exporttxt Pen4TextFileName
exportformat 1 4 0 0 3
exporttxt Pen5TextFileName
exportformat 1 5 0 0 3
exporttxt Pen6TextFileName
exportformat 1 6 0 0 3
exporttxt Pen7TextFileName
exportformat 1 7 0 0 3
exporttxt Pen8TextFileName
exportformat 1 8 0 0 3
exporttxt Pen9TextFileName
```

```
exportformat 1 9 0 0 3
exporttxt Pen10TextFileName
message Done!
```

exportformat

exportformat filePreference penNumberIndex phaseType dataType decimalPrecision<CR>

filePreference – Parameter to control the addition of date, time and instrument serial number to the file name. When set to 0 no text will be appended and will overwrite a previous file without prompting. When set to 1 the date, time and instrument serial number are appended. This parameter alters all export file name preferences and the savegraph command too.

penNumberIndex – Parameter to specify the zero based pen index (0..9) for pens 1 to 10 to export in ASCII text format.

phaseType – Parameter to specify the phase export ASCII data, 0 for 360 degrees and 1 for 180 degrees.

dataType – Parameter to specify the amplitude / impedance export ASCII data, 0 for gain / impedance and 1 for loss / admittance.

decimalPrecision – Parameter to specify the decimal precision of the ASCII text data.0 to 9 representing the number of decimal places required.

This command specifies the output file-naming format for all files exported via a script command. It also specifies the pen number, phase data, amplitude / impedance data types and the decimal precision of the data for text exported via a script command. The file preference parameter gives the user the ability to either generate an individual file name for each export or to overwrite an existing file. This is useful if the CypherGraph application is used to acquire data for automated testing. The data acquired can be exported to a text file where it can be further processed by another application.

Example:

```
exportformat 1 0 0 0 3
exporttxt Pen1TextFileName
exportformat 1 1 1 0 3
exporttxt Pen2TextFileName
exportformat 1 2 1 1 3
exporttxt Pen3TextFileName
exportformat 1 3 0 0 3
exporttxt Pen4TextFileName
exportformat 1 4 0 0 3
exporttxt Pen5TextFileName
exportformat 1 5 0 0 3
exporttxt Pen6TextFileName
exportformat 1 6 0 0 3
exporttxt Pen7TextFileName
exportformat 1 7 0 0 3
exporttxt Pen8TextFileName
exportformat 1 8 0 0 3
exporttxt Pen9TextFileName
exportformat 1 9 0 0 3
exporttxt Pen10TextFileName
message Done!
```

exportwmf

exportwmf wmfFileName<CR>

wmfFileName – Optional file name of the Windows meta file without the file extension (.wmf)

This command exports a Windows meta file image of the graph to the export folder using the file name specified. If the file name is omitted then the user is prompted to enter one. If no file name is entered then the file is not saved. File paths are not allowed, only the file name. Windows file name character restrictions apply.

Example:

```
exportformat 1
exportwmf WmfFileName
message Done!
```

I

idlefreq

idlefreq idleFrequency<CR>

idleFrequency – Parameter to specify the oscillator output frequency in Hz

Command to set the oscillator idle output frequency. If the function is passed a zero then the oscillator output is switched off when not testing and a value of -1 should be passed for start frequency.

Example:

```
idlefreq 0
prompt Check that there is no output sine wave
sweepmode 0
startfreq 1000
idlefreq -1
prompt Check that the output frequency is 1KHz
idlefreq 2000
prompt Check that the output frequency is 2KHz
```

imptest

imptest startFrequency endFrequency numPoints<CR>

startFrequency – Optional parameter to specify the starting frequency (A) in Hz
endFrequency – Optional parameter to specify the ending frequency (B) in Hz
numTestPoints – Optional parameter to specify the number of test points to use

This is a command to start an impedance test. Three optional parameters can be passed to the command these are start frequency (A), end frequency (B) and number of points. The test is then started. If the command is passed without additional parameters the settings are as previously set or default if not specified by another command. Before this command is executed a document should be opened with newimpf, amptest or loadgraph commands.

Example:

```
loadgraph CypherScriptImp.gzd
atten 0
linear 0
startfreq 1000
endfreq 3000
imptest
legend 0dB
wait
```

L

legend

legend penLegendText<CR>

penLegendText – Parameter that specifies the current pen legend text

A command to legend a pen.

Example:

```
newampf My Graph
imptest 1000 3000
legend Pen Legend Text
wait
```

linear

linear pointInterval<CR>

pointInterval – Parameter to specify logarithmic or linear frequency point intervals

Command to specify the frequency test points interval spacing. A parameter value of 1 specifies linear frequency intervals and a value of 0 specifies logarithmic frequency intervals.

Example:

```
linear 0
amptest
legend Logarithmic test points
wait
linear 1
amptest
legend Linear test points
wait
title Linear / logarithmic test
prompt Linear / logarithmic function test complete
```

loadgraph

loadgraph graphFileName<CR>

graphFileName – Parameter specifying the file name of a graph to open

This command loads an existing graph residing in the Plots folder of the hard disk. The file name must be specified including the file extension. Windows file name restrictions apply. This allows the user to configure the view of a graph prior to running a script, including a mask and then load the graph during script processing.

```
loadgraph CypherScriptAmp.gad
atten 0
linear 0
startfreq 1000
endfreq 3000
amptest
legend Test 1
wait
```

M

message

message messageText<CR>

messageText – The text string. This can be a maximum of 62 characters

Command to bring up an information dialog box containing the message text. This command does not halt script processing.

Example:

```
message Done!
```

N

newampf

newampf graphTitleText<CR>

graphTitleText – Optional parameter to specify the title text of the graph

This command creates a new amplitude vs. frequency document. The title of the graph can optionally be specified in the command.

Example:

```
newampf Amplitude
sleep 100
prompt A new amplitude document
close
```

newimpf

newampf graphTitleText<CR>

graphTitleText – Optional parameter to specify the title text of the graph

This command creates a new impedance vs. frequency document. The title of the graph can optionally be specified in the command.

Example:

```
newimpf Impedance
sleep 100
prompt A new impedance document
close
```

P

period

period testPeriod<CR>

testPeriod – Parameter to specify the test period time in mS

Command to set the test period time, which is the time between a change in the oscillator's frequency and when the amplitude / impedance and phase measurements are made.

phase

phase phaseOption<CR>

phaseOption – Parameter to specify phase data collection on = 1 or off = 0

Command to enable or disable the acquisition of phase data.

Example:

```
phase 1
```

points

points numPoints<CR>

numPoints – Parameter to specify the number of test points

Command to set the number of test points to use when not specified in the XREF-amptest or XREF-imptest commands.

printgraph

printgraph paperOrientation<CR>

paperOrientation – Parameter specifies the orientation in which to print the graph

The command prints the graph. The paper orientation parameter specifies portrait when 0 and landscape when 1.

Example:

```
printgraph 0
```

prompt

prompt promptText<CR>

promptText – Text string to appear in the prompt dialog box.

This command launches a dialog box containing the text string. It halts script processing until the user clicks to OK button. This command is designed to halt script processing until the operator has acknowledged and responded to the prompt text.

Example:

```
newimpf Impedance
prompt A new impedance document
close
```

promptabort

promptabort promptText<CR>

This command launches a dialog box containing the text string. It halts script processing until the user clicks the 'Yes' or 'No' buttons. If the user clicks the 'Yes' button, further script processing is aborted. If the user clicks the 'No' button, script processing is resumed.

Example:

```
# Prompt to quit the application
promptabort Do you wish to continue using CypherGraph?
# If the user clicks 'Yes' then the script is aborted and the quit command is not processed
quit
# eof
```

prompnottabort

promptnotabort promptText<CR>

This command launches a dialog box containing the text string. It halts script processing until the user clicks the 'Yes' or 'No' buttons. If the user clicks the 'No' button, further script processing is aborted. If the user clicks the 'Yes' button, script processing is resumed.

Example:

```
# Prompt to quit the application
prompnottabort Do you wish to exit CypherGraph?
# If the user clicks 'No' then the script is aborted and the quit command is not processed
quit
# eof
```

Q

quit

quit<CR>

This command quits the CypherGraph program. No parameters are required. The user will be prompted to save any un-saved documents. This is useful if CypherGraph is to be used as a part of an automated test procedure, where the application is launched, performs some tests, exports the data and then quits allowing further processing of the data to be performed.

Example:

```
quit
```

S

savegraph

savegraph graphFileName<CR>

graphFileName – Optional text string of the file name to use when saving the graph

This command saves the graph with the file name specified. If no file name is specified in the command the user is prompted to enter one. If the user does not enter a file name the file is not saved. File paths are not allowed, only the file name. Windows file name character restrictions apply. The file extension should be omitted since this will be added automatically based on the type of graph being saved.

Example:

```
# Save the graph
savegraph My Graph
```

setpen

setpen penIndex<CR>

penIndex – The zero based index of the pen to use (0..9)

Command to select a new pen. The command requires a number from 0 to 9 specifying the pen number 1 to 10.

Example:

```
newampf Amplitude tests
points 424

# lazy way of setting the start and end frequency
# saves typing the same numbers at the end of each amptest or imptest
# command. Also means groups of test can be changed easily

startfreq 1000
endfreq 1000000

atten 0
setpin 8
sleep 100
amptest
legend Black
wait

setpin 9
sleep 100
amptest
legend Brown
wait

setpin 10
sleep 100
amptest
legend Red
wait

setpin 11
sleep 100
amptest
legend Orange
wait

# Skip yellow pen
setpen 5

setpin 12
sleep 100
amptest
legend Green
wait
```

setpin

setpin pinCode<CR>

pinCode – Parameter to specify the code presented to the output control pins

The instrument has a six bit digital output facility, which can be used to control an external hardware multiplexer. This enables the user to select different hardware configurations prior to performing a test. The 'setpin' command controls this digital code. The table in Figure 3 shows the relationship between the parameter number and the logical state of the output terminals.

The pinCode is a decimal number in the range 0 to 63, that is interpreted as a six bit binary number, D5 (msb) to D0 (lsb). This can be calculated from the series:-

pinCode Number = D5·(32) + D4·(16) + D3·(8) + D2·(4) + D1·(2) + D0

where the 'D' references can be a 1 or 0.

The table in Figure 3 shows the relation ship between the parameter number and the logical state of the output terminals.

D5	D4	D3	D2	D1	D0	Number
0	0	0	0	0	0	0
0	0	0	0	0	1	1
0	0	0	0	1	0	2
0	0	0	0	1	1	3
0	0	0	1	0	0	4
0	1	0	0	0	0	16
0	1	0	0	0	1	17
1	1	1	1	1	0	62
1	1	1	1	1	1	63

Figure 3 Pin code number to output table

sleep

sleep timeIn_mS<CR>

This command causes script processing to halt for the specified time period in milliseconds. During portions of script processing the user may wish script processing to pause to let analogue signals settle. An example of this would be when changing a the pin code which controls a de-multiplexer driving channel selection relays. Because the relays will mechanically bounce and a DC offset may have been introduced into the device under test a small pause is required before test can continue.

Example:

```
sleep 100
```

startfreq

startfreq startingFrequency<CR>

startingFrequency – Parameter to specify the starting frequency in Hz.

Command to set the test start frequency to use when not specified in the test command.

Example:

```
startfreq 1000
```

sweepmode

sweepmode sweepDirection<CR>

sweepDirection – Parameter to specify the sweep direction.

This command controls the direction of sweep. Set the parameter to 0 to sweep from the start frequency (A) to the end frequency (B). Set the parameter to 1 to reverse the direction (B to A). Finally a value of 2 will alternate between forward (A to B) and reverse (B to A).

```
sweepmode 2
```

T

title

title graphTitleText<CR>

graphTitleText – Text string of the required title.

Command to set the graph title. If the title text is omitted then the user is prompted to enter one. If the user fails to enter a title it is unchanged.

W

wait

wait<CR>

Command to halt command processing until the current test has completed. This command should always follow the amptest or imptest commands.

Appendix D

Installing CypherGraph

The CypherGraph software requires Windows '98SE with Internet Explorer 4 (or higher), ME, 2000, or XP. The basic installation procedure is the same for all operating systems however the installation of the device driver for the C60 varies slightly. The device driver is included on the CypherGraph software CD and it is advised that the CD is in the CD-ROM drive when the C60 is plugged in for the first time.

When the CypherGraph application is opened it will connect to the first instrument that it finds. If CypherGraph is already opened and the status bar reports that the instrument is disconnected (bottom left hand corner of the application window) then click the USB icon on the horizontal tool bar. This will open the Select Instrument dialog box. Choose the device to connect to from the drop down list box. If there are no instruments listed, make sure that the instrument is connected and click the 'Refresh' button. Click 'OK' to connect to the device.

If CypherGraph does not display any devices in the drop down list when the refresh button is pressed and the C60 is connected, then follow the instructions in the Device driver update section to ensure that the device driver has been properly installed.

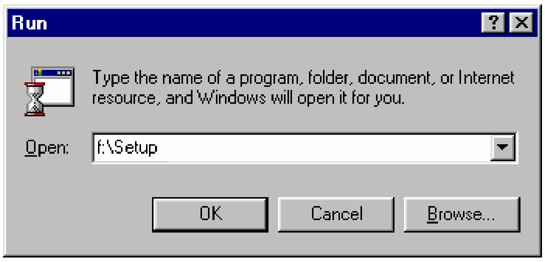
Installation on Windows '98

CypherGraph Software

1. Quit all open applications.

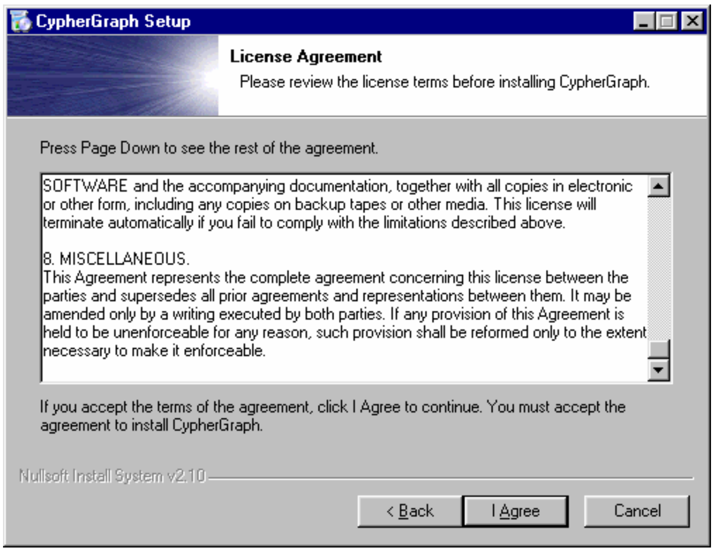
2. If your computer has auto run enabled, then the software will automatically install. Insert the CypherGraph Software CD into the CD-ROM drive and the installation will begin. Skip the next instruction.

3. If your computer has auto run disabled, then insert the CD into the drive and wait for the operating system to read the disk. Hold the Windows key down and press the R key to open the Run dialog. Type the drive letter of the CypherGraph software CD followed by ':\setup'. Click the OK button.



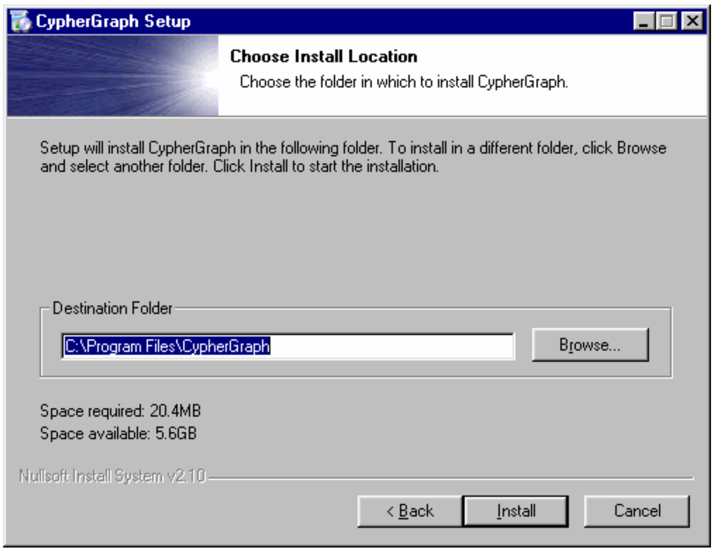
4. The dialog box - 'Welcome to the CyperGraph Setup Wizard' will appear. Click the 'Next>' button.

5. The 'License Agreement' box follows. Read it and if it is satisfactory, click 'I Agree'.

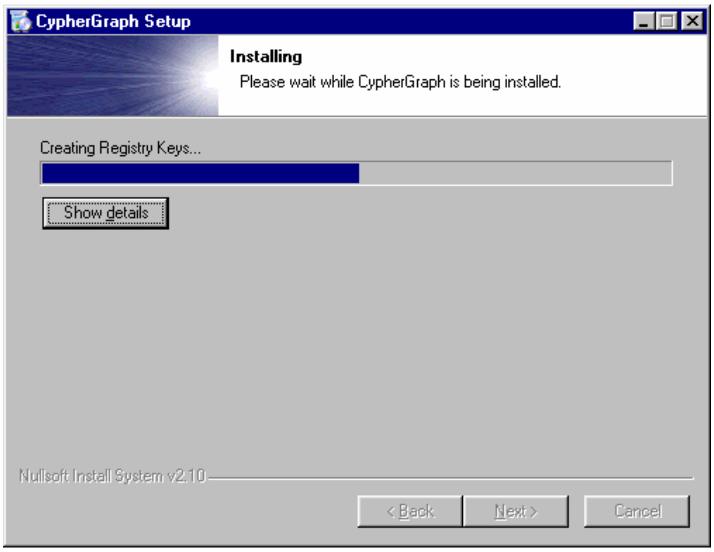


6. If you already have CypherGraph installed on your PC, then you are prompted to uninstall the existing version (recommended).

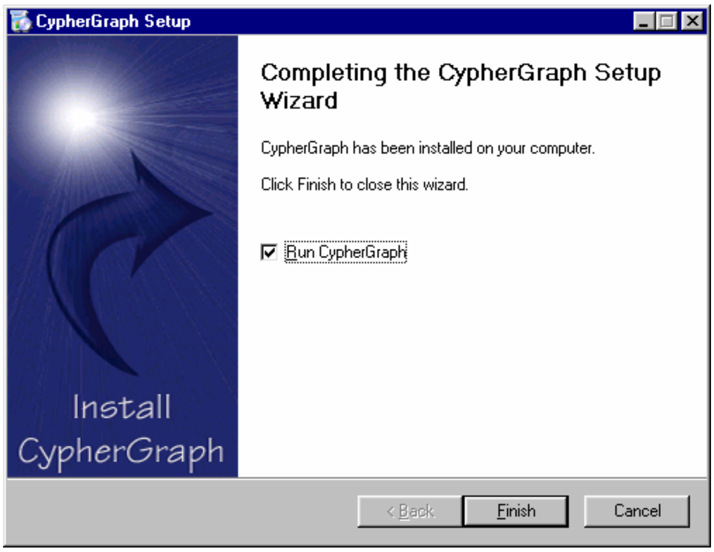
7. If this is a fresh installation, the 'Choose Install Location' box will appear. The usual location for the software is C:\Program Files\CypherGraph\. Click 'Install'.



8. The installer will now copy all the required files to your PC. If a dialog asks you to reset your PC now click 'No' and continue with the install.



9. Once the installer has finished copying the files you can choose to start the CypherGraph application by clicking finish. If you do not wish to run the application then uncheck the Run CypherGraph check box and click finish.



10. The C60 can now be connected to the PC via the USB lead. After a short period the Windows will re-build the device driver data base and then automatically install the device driver.

11. Remove the CD. Keep the CD is a safe place, for future use by you or your colleagues.

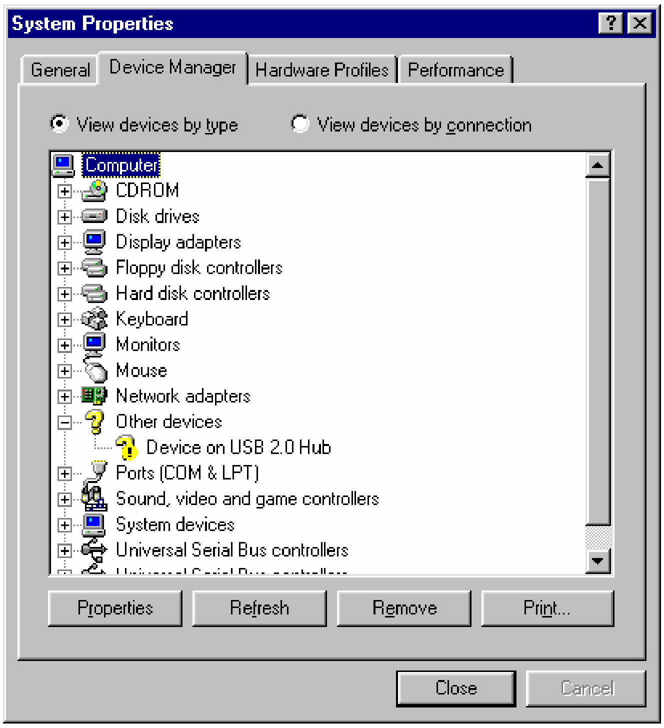
Device driver update

If the C60 was plugged in before the CypherGraph software was installed then Windows may not have located the device driver for the instrument. Follow the instructions below to perform a re-install of the device driver after CypherGraph software has been installed.

1. Insert the CypherGraph Software CD into the CD-ROM drive. If the CypherGraph installer opens then click 'Cancel' and then 'Yes' to quit.

2. Plug in the C60.

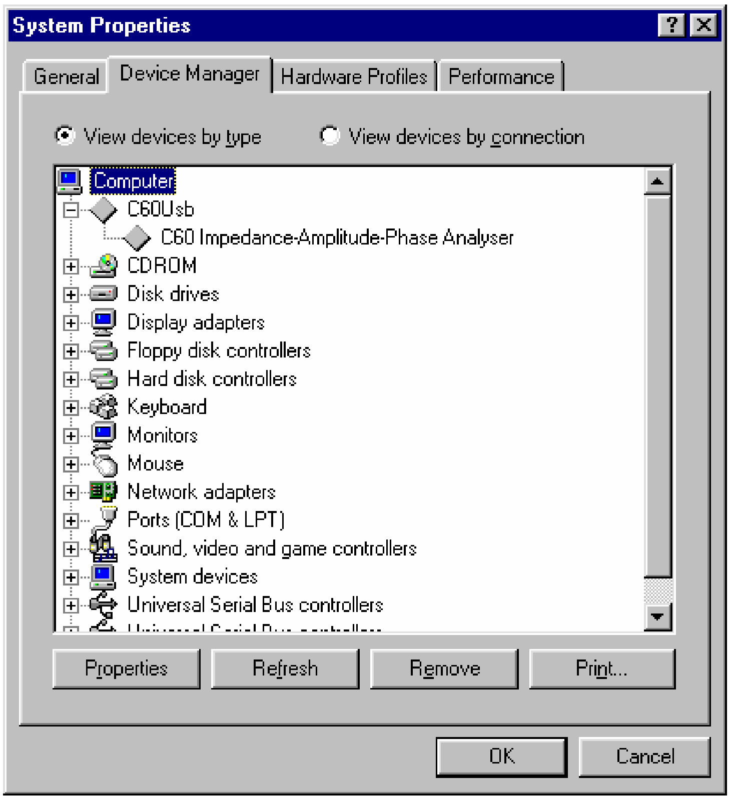
3. Open the Device Manager by right clicking on the 'my computer' icon then left clicking properties. Then select the device manager tab in the System Propertied dialog box. If windows has failed to find a device driver for the instrument then this will be represented by yellow question mark in the device manager.



4. Click on the 'Device' icon and press the delete key. Click 'Yes' to confirm removal of the device.

5. Disconnect and reconnect the C60. Windows will now install the driver automatically. This may take a short time as Windows re-builds its device driver data base and copies the driver files.

6. The screen shot below shows the device driver has been properly installed.



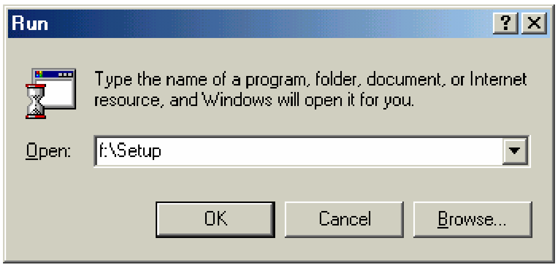
Installation on Windows ME

CypherGraph Software

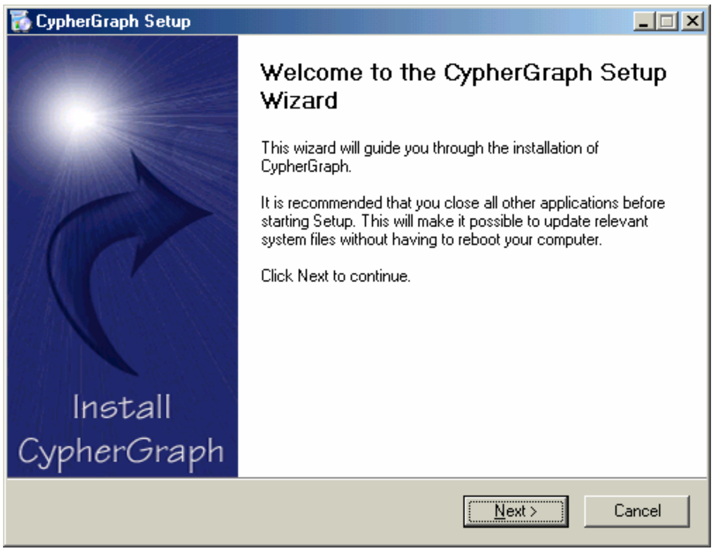
1. Quit all open applications.

2. If your computer has auto run enabled, then the software will automatically install. Insert the CypherGraph Software CD into the CD-ROM drive and the installation will begin. Skip the next instruction.

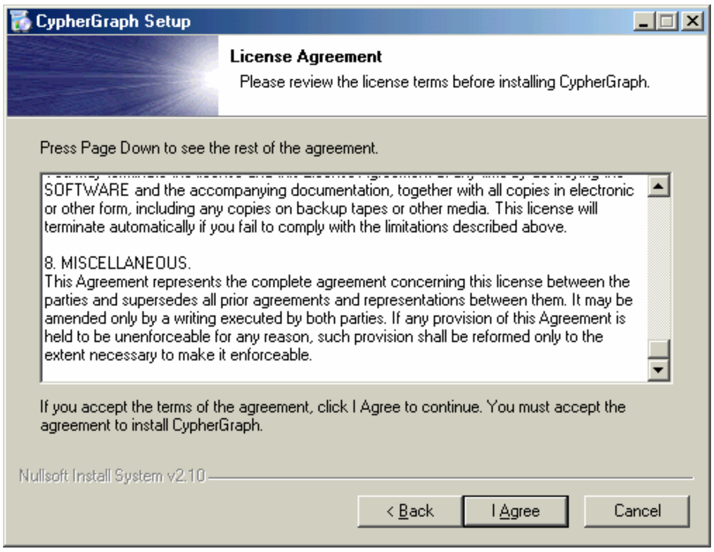
3. If your computer has auto run disabled, then insert the CD into the drive and wait for the operating system to read the disk. Hold the Windows key down and press the R key to open the Run dialog. Type the drive letter of the CypherGraph software CD followed by ':\setup'. Click the OK button.



4. The dialog box - 'Welcome to the CyperGraph Setup Wizard' will appear. Click the 'Next>' button.

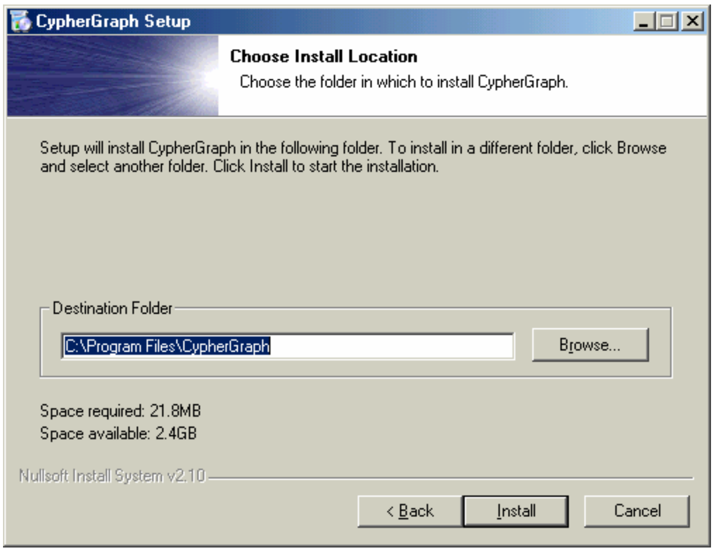


5. The 'License Agreement' box follows. Read it and if it is satisfactory, click 'I Agree'.

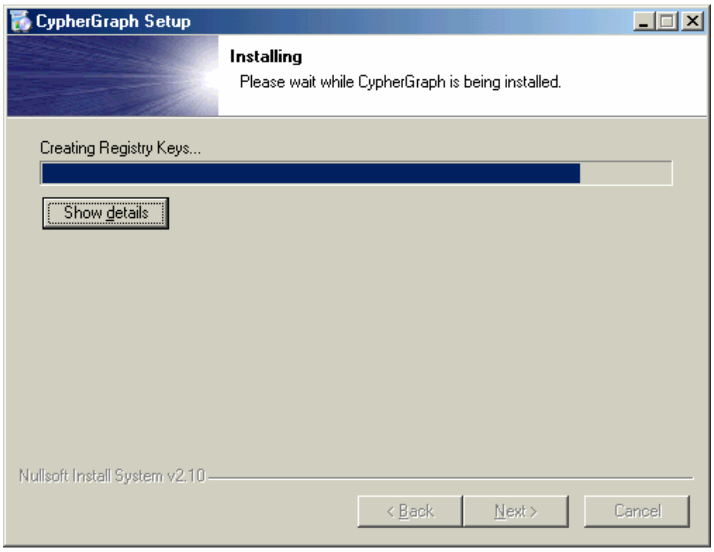


6. If you already have CypherGraph installed on your PC, then you are prompted to uninstall the existing version (recommended).

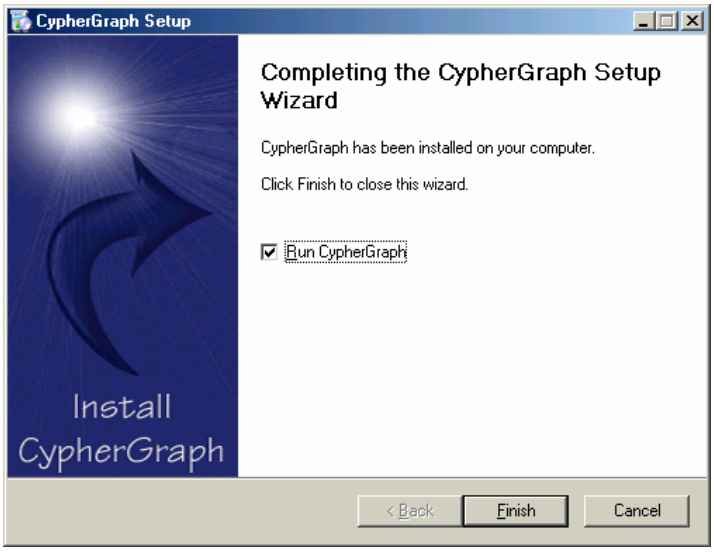
7. If this is a fresh installation, the 'Choose Install Location' box will appear. The usual location for the software is C:\Program Files\CypherGraph\. Click 'Install'.



8. The installer will now copy all the required files to your PC. If a dialog asks you to reset your PC now click 'No' and continue with the install.



9. Once the installer has finished copying the files you can choose to start the CypherGraph application by clicking finish. If you do not wish to run the application then uncheck the Run CypherGraph check box and click finish.



10. The C60 can now be connected to the PC via the USB lead. After a short period the Windows will re-build the device driver data base and then automatically install the device driver.

11. Remove the CD. Keep the CD is a safe place, for future use by you or your colleagues.

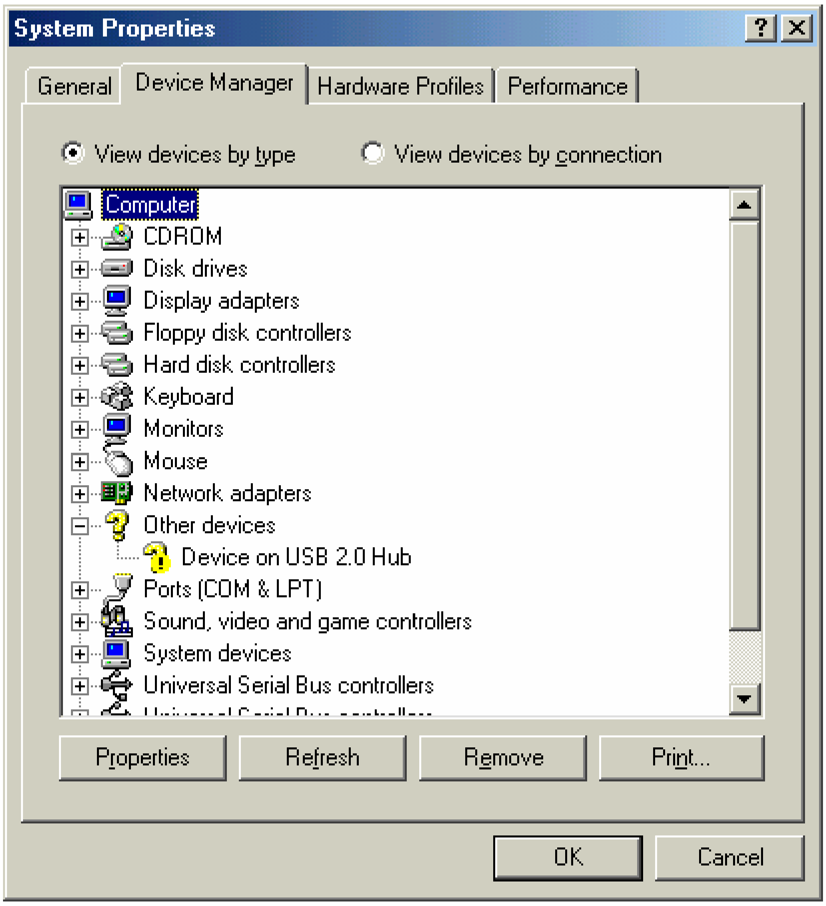
Device driver update

If the C60 was plugged in before the CypherGraph software was installed then Windows may not have located the device driver for the instrument. Follow the instructions below to perform a manual install of the device driver after CypherGraph software has been installed.

1. Insert the CypherGraph Software CD into the CD-ROM drive. If the CypherGraph installer opens then click 'Cancel' and then 'Yes' to quit.

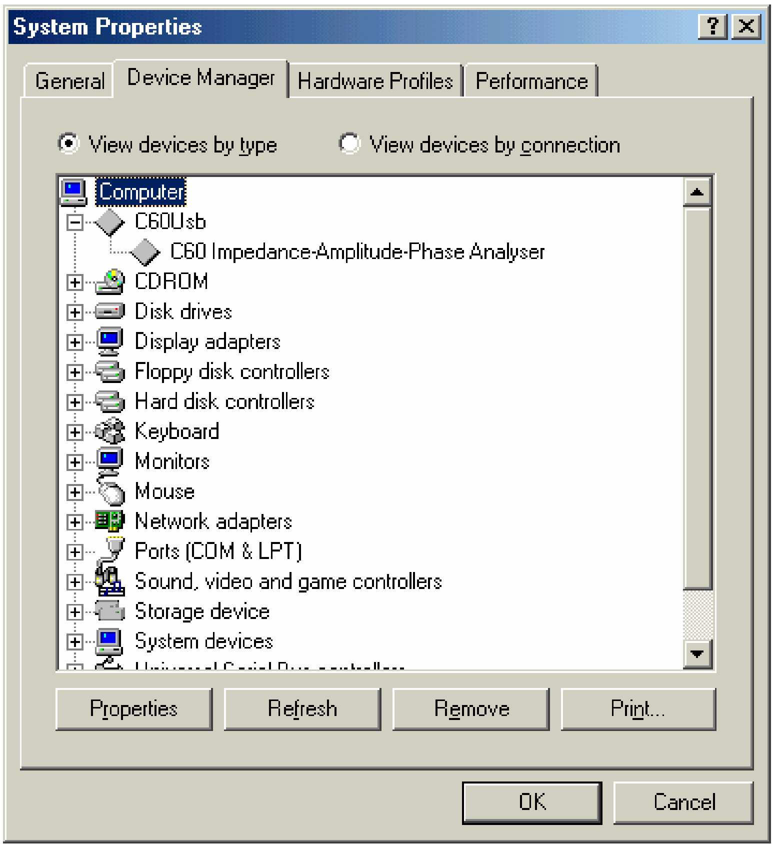
2. Plug in the C60.

3. Open the Device Manager by right clicking on the 'my computer' icon then left clicking properties. Then select the device manager tab in the System Propertied dialog box. If windows has failed to find a device driver for the instrument then this will be represented by a yellow question mark in the device manager.



4. Click on the 'Device' icon and press the delete key. Click 'Yes' to confirm removal of the device.

5. Disconnect and reconnect the C60. Windows will now install the driver from the CD. The screen shot below shows the device driver has been properly installed.



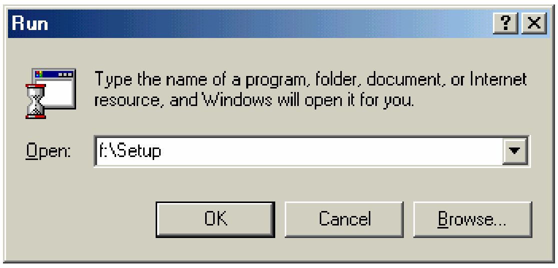
Installation on Windows 2000

CypherGraph Software

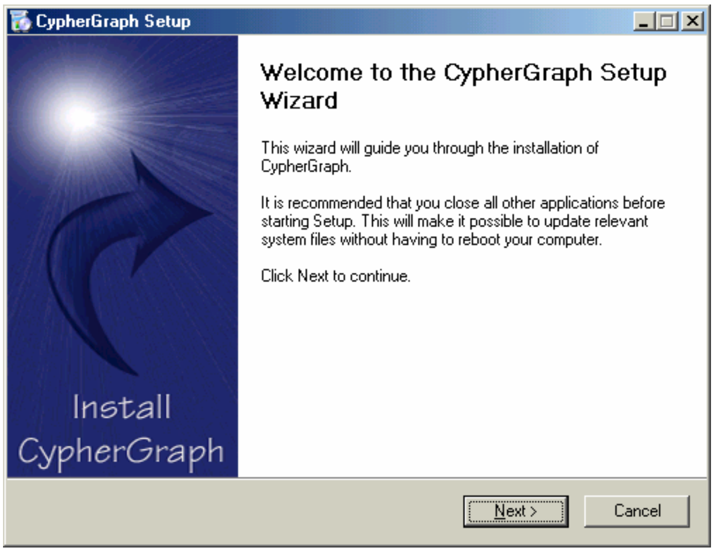
1. Quit all open applications.

2. If your computer has auto run enabled, then the software will automatically install. Insert the CypherGraph Software CD into the CD-ROM drive and the installation will begin. Skip the next instruction.

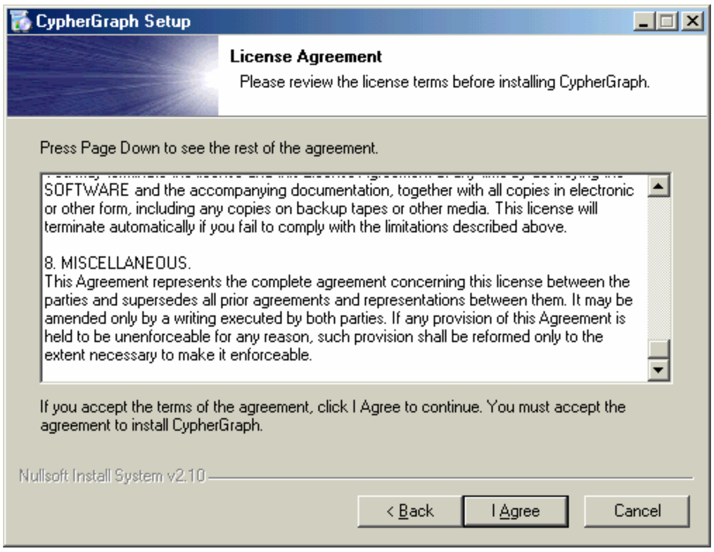
3. If your computer has auto run disabled, then insert the CD into the drive and wait for the operating system to read the disk. Hold the Windows key down and press the R key to open the Run dialog. Type the drive letter of the CypherGraph software CD followed by ':\setup'. Click the OK button.



4. The dialog box - 'Welcome to the CypherGraph Setup Wizard' will appear. Click the 'Next>' button.

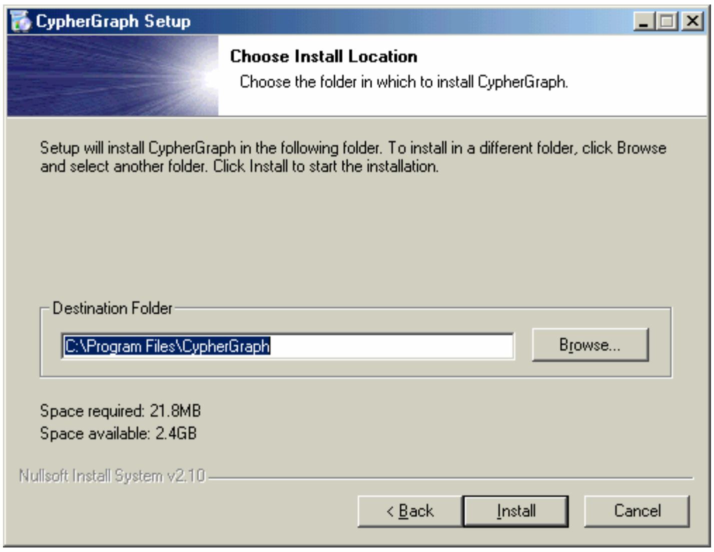


5. The 'License Agreement' box follows. Read it and if it is satisfactory, click 'I Agree'.

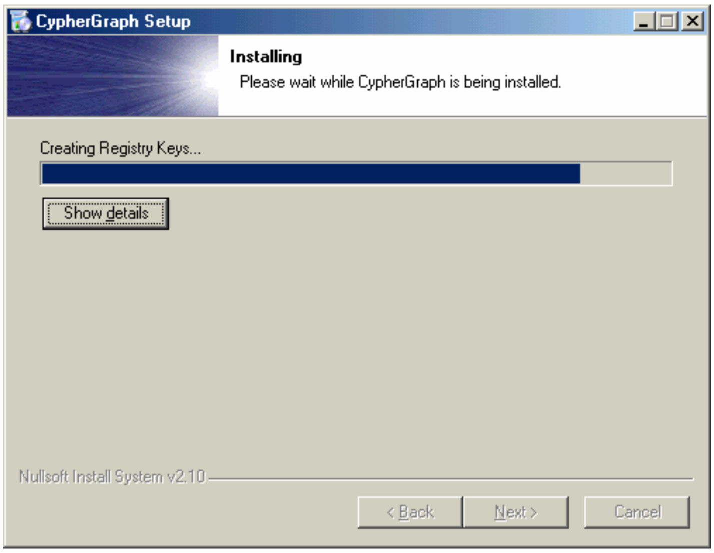


6. If you already have CypherGraph installed on your PC, then you are prompted to uninstall the existing version (recommended).

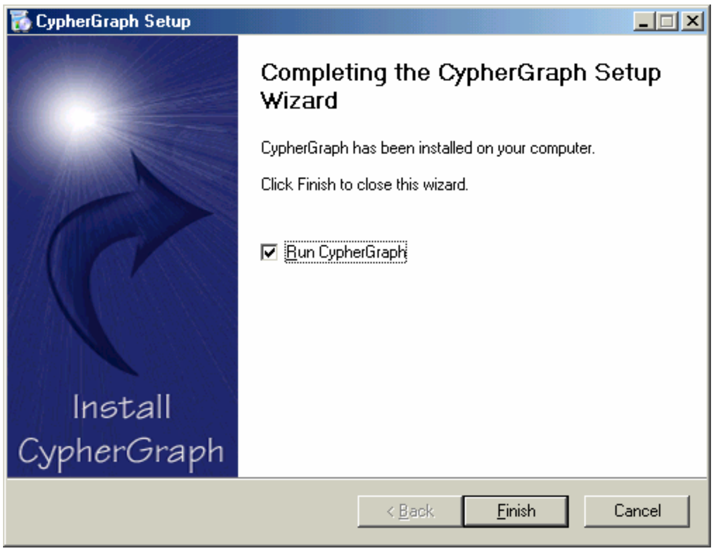
7. If this is a fresh installation, the 'Choose Install Location' box will appear. The usual location for the software is C:\Program Files\CypherGraph\. Click 'Install'.



8. The installer will now copy all the required files to your PC. If a dialog asks you to reset your PC now click 'No' and continue with the install.



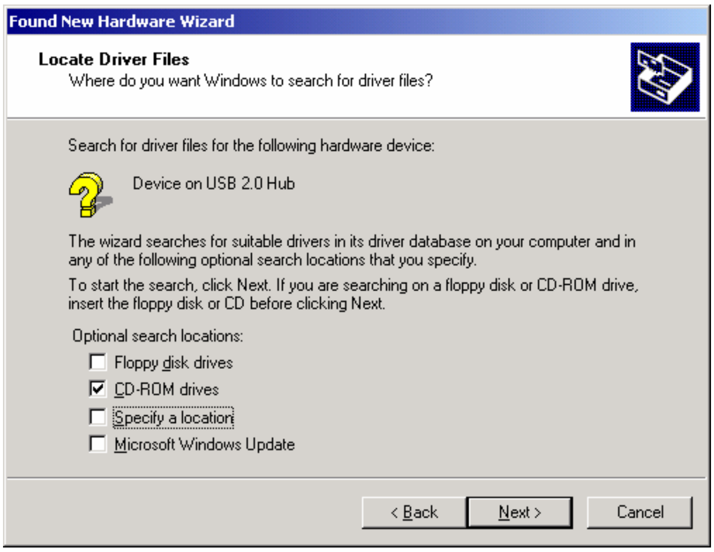
9. Once the installer has finished copying the files you can choose to start the CypherGraph application by clicking finish. If you do not wish to run the application then uncheck the Run CypherGraph check box and click finish.



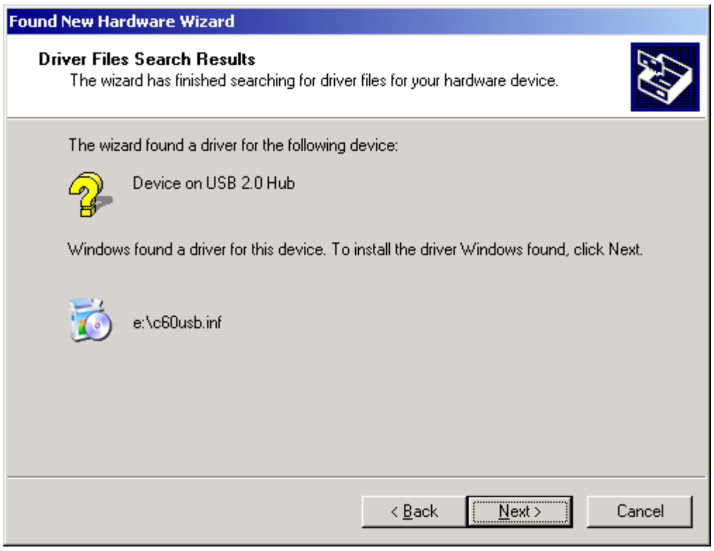
10. The C60 can now be connected to the PC via the USB lead. After a short period the Windows will open the found new device wizard. Click 'Next >' to continue.

11. Select the 'Search for a suitable driver for my device (recommended)' option and click 'Next >' to continue.

12. Check the 'CD-ROM drives' box and click 'Next >' to continue.



13. The Found New Hardware Wizard should now find the driver on the CypherGraph Software CD. Click 'Next >' to install the driver.



14. Click 'Finish' to complete the driver installation

15. Remove the CD. Keep the CD is a safe place, for future use by you or your colleagues

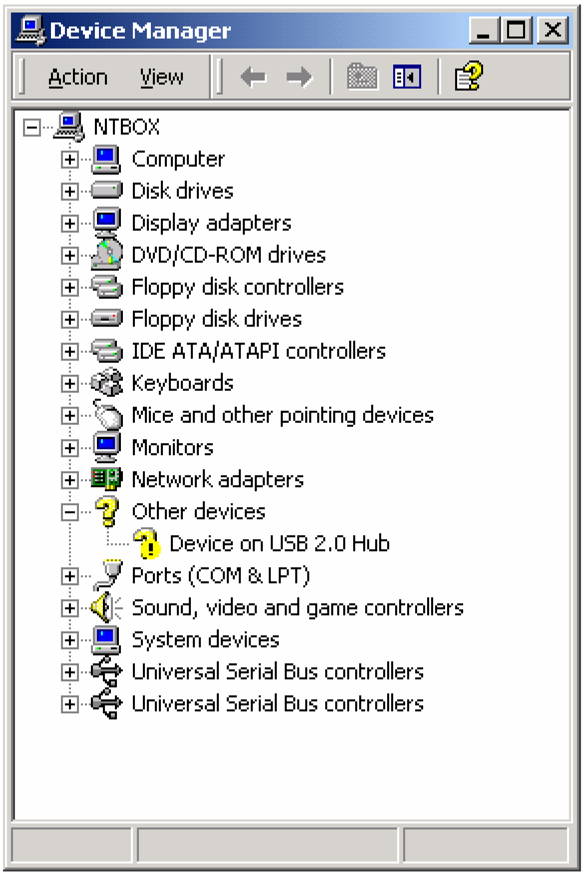
Device driver update

If the C60 was plugged in before the CypherGraph software was installed then Windows may not have located the device driver for the instrument. Follow the instructions below to perform a manual install of the device driver after CypherGraph software has been installed.

1. Insert the CypherGraph Software CD into the CD-ROM drive. If the CypherGraph installer opens then click 'Cancel' and then 'Yes' to quit.

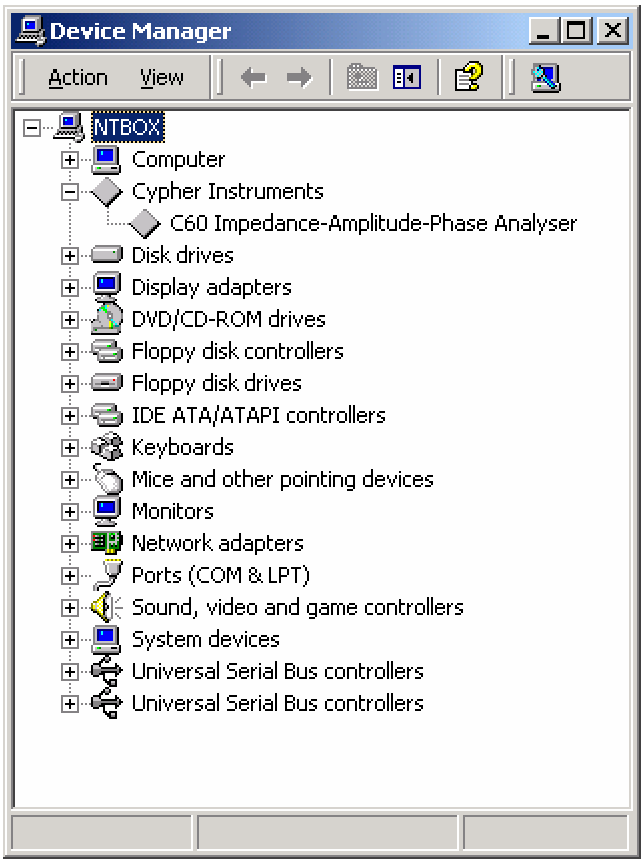
2. Plug in the C60.

3. Open the Device Manager by right clicking on the 'my computer' icon then left clicking properties. Then select the device manager tab in the System Propertied dialog box. If windows has failed to find a device driver for the instrument then this will be represented by an exclamation mark in a yellow in the device manager.



4. Click on the 'C60 Impedance-Amplitude-Phase Analyser' icon and press the delete key.

5. Disconnect and reconnect the C60. Windows will now install the driver from the CD. The screen shot below shows the device driver has been properly installed.



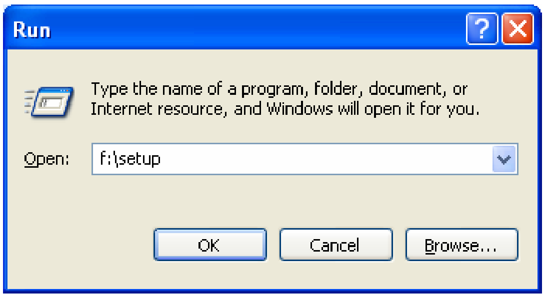
Installation on Windows XP

CypherGraph Software

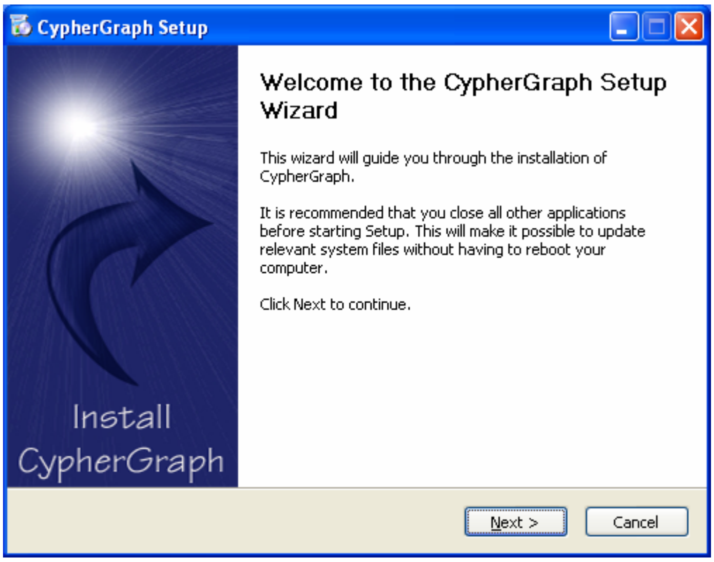
1. Quit all open applications.

2. If your computer has auto run enabled, then the software will automatically install. Insert the CypherGraph Software CD into the CD-ROM drive and the installation will begin. Skip the next instruction.

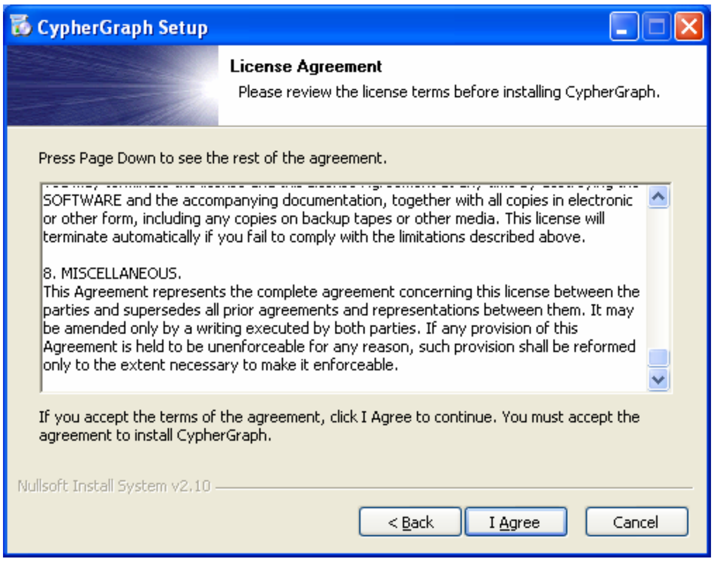
3. If your computer has auto run disabled, then insert the CD into the drive and wait for the operating system to read the disk. Hold the Windows key down and press the R key to open the Run dialog. Type the drive letter of the CypherGraph software CD followed by ':\setup'. Click the OK button.



4. The dialog box - 'Welcome to the CyperGraph Setup Wizard' will appear. Click the 'Next>' button.

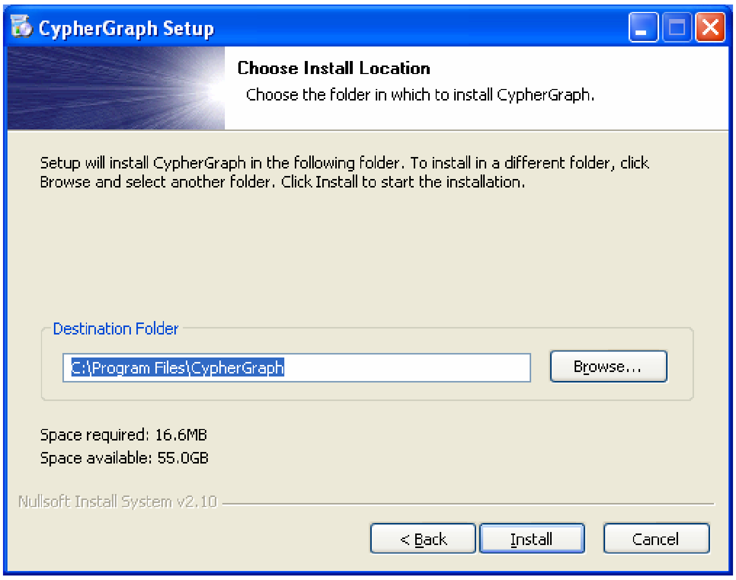


5. The 'License Agreement' box follows. Read it and if it is satisfactory, click 'I Agree'.

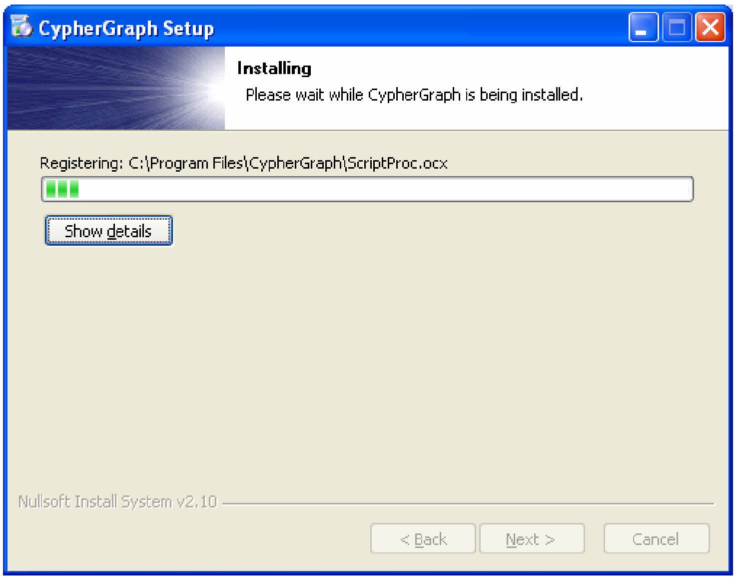


6. If you already have CypherGraph installed on your PC, then you are prompted to uninstall the existing version (recommended).

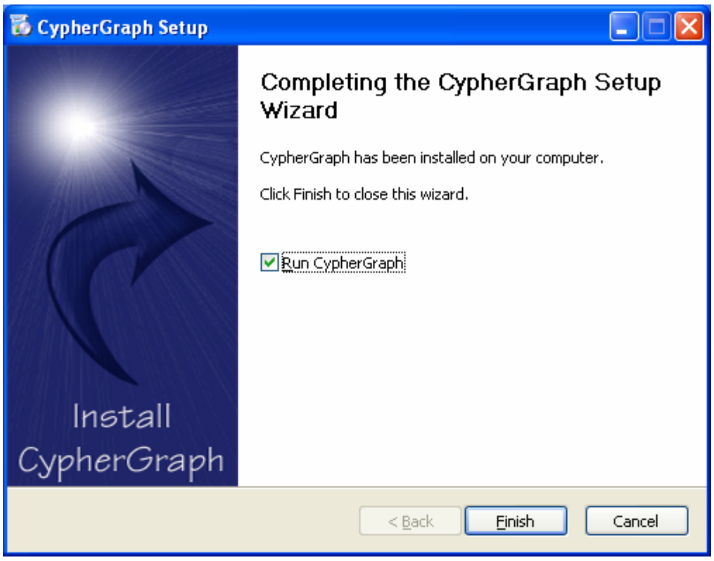
7. If this is a fresh installation, the 'Choose Install Location' box will appear. The usual location for the software is C:\Program Files\CypherGraph\. Click 'Install'.



8. The installer will now copy all the required files to your PC. If a dialog asks you to reset your PC now click 'No' and continue with the install.



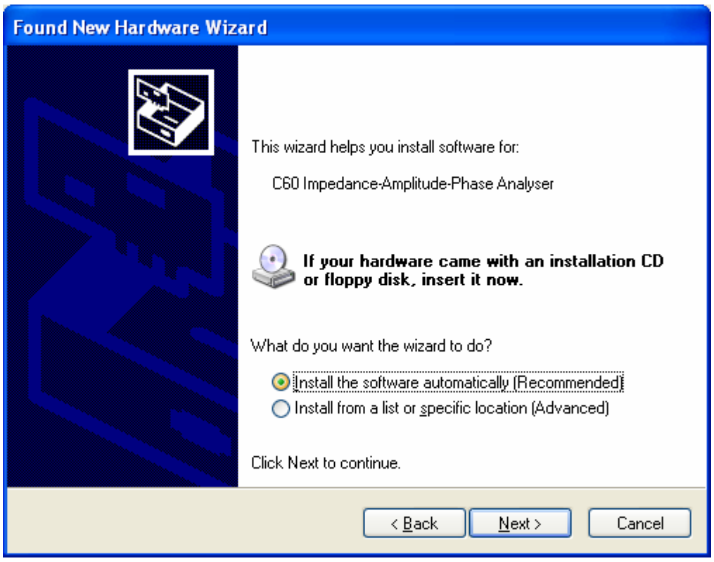
9. Once the installer has finished copying the files you can choose to start the CypherGraph application by clicking finish. If you do not wish to run the application then uncheck the Run CypherGraph check box and click finish.



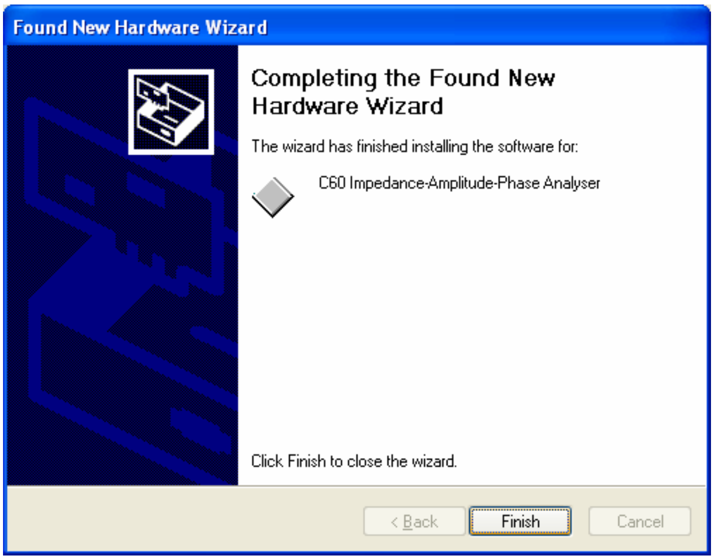
10. There is no other action needed, other than to remove the CD. Keep the CD is a safe place, for future use by you or your colleagues.

11. The C60 can now be connected to the PC via the USB lead. After a short period the Found New Hardware Wizard dialog will appear. Check the radio dial labelled 'No, not this time'. Click the 'Next >' button.

12. Check the radio dial labelled 'Install the software automatically (Recommended)' and click 'Next >'.



13. Click 'Finish' to complete the driver installation.



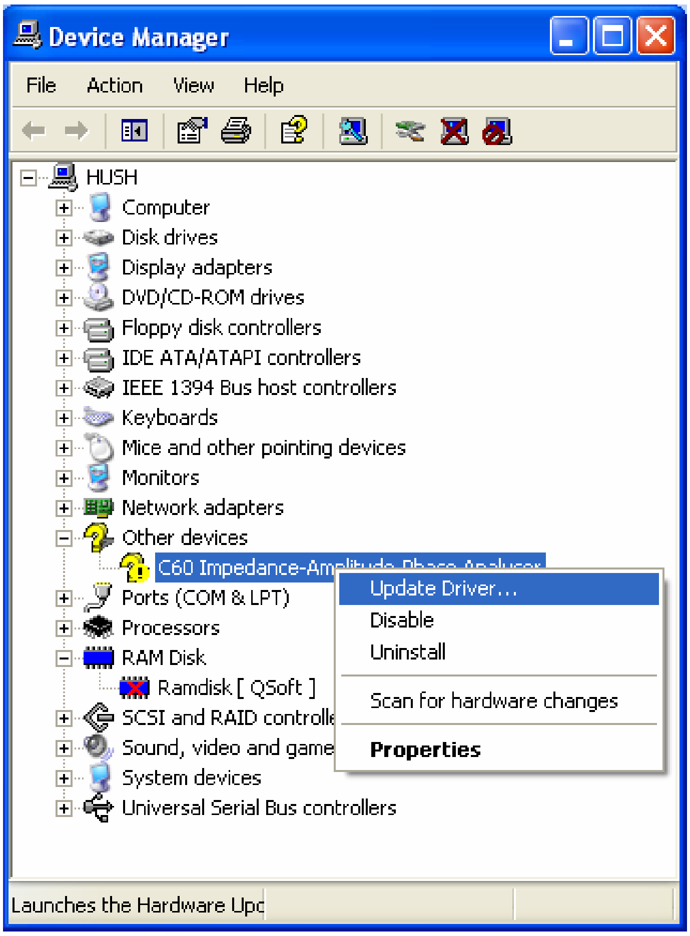
Device driver update

If the C60 was plugged in before the CypherGraph software was installed then Windows may not have located the device driver for the instrument. Follow the instructions below to perform a manual install of the device driver after CypherGraph software has been installed.

1. Insert the CypherGraph Software CD into the CD-ROM drive. If the CypherGraph installer opens then click 'Cancel' and then 'Yes' to quit.

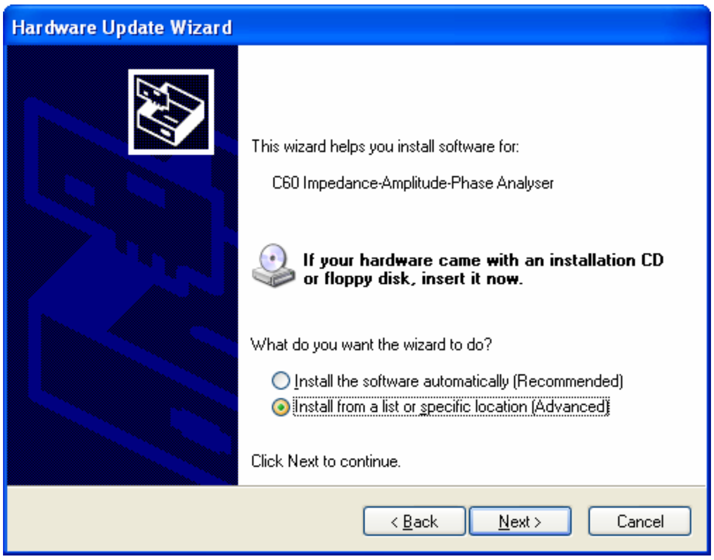
2. Plug in the C60.

3. Open the Device Manager by right clicking on the 'my computer' icon then left clicking properties. Then select the hardware tab in the System Propertied dialog box and click the Device Manager button. If windows has failed to find a device driver for the instrument then this will be represented by a yellow question mark in the device manager next to the C60 Impedance-Amplitude-Phase Analyser device. Right click on the icon and left click 'Update Driver'.

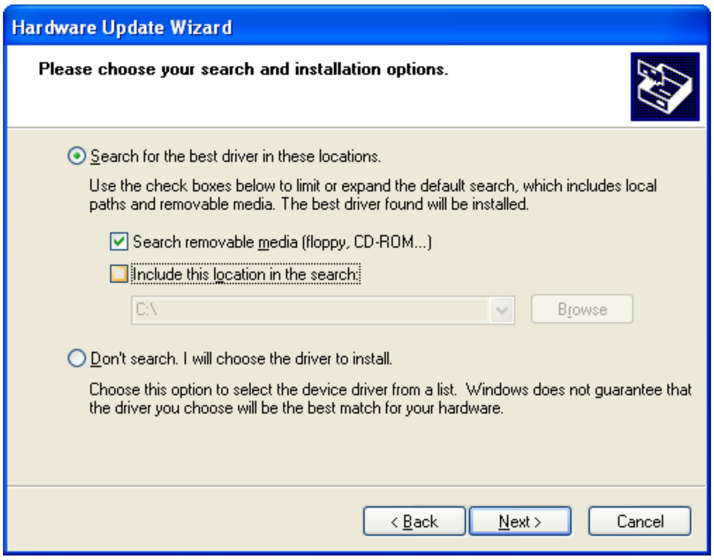


4. The Wizard dialog will appear. Check the radio dial labelled 'No, not this time'. Click 'Next >' to continue.

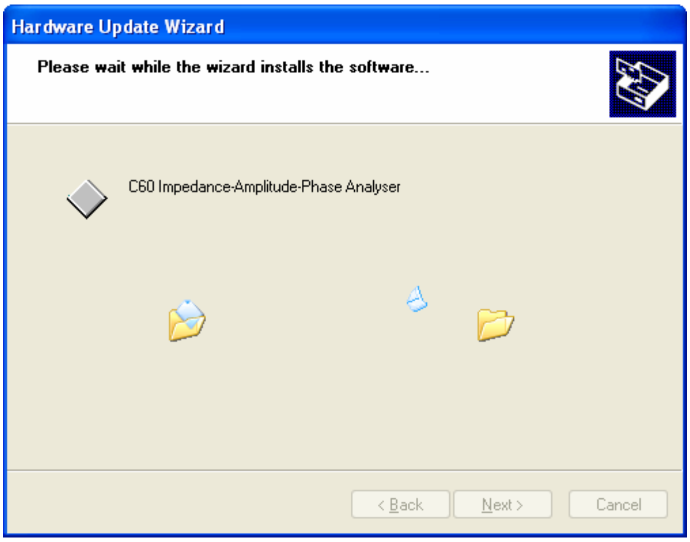
5. Select the 'Install from a list or specific location(Advanced) option. Click 'Next >' to continue.



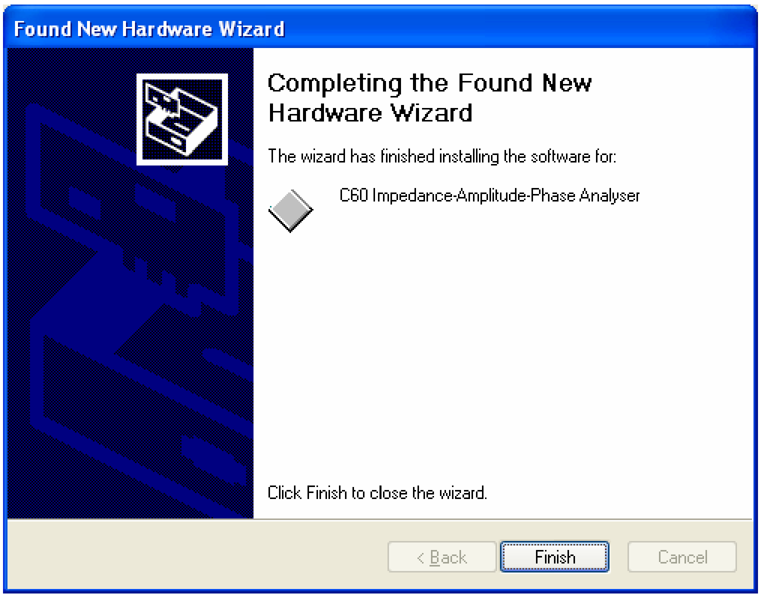
6. Check the 'Search removable medial (floppy, CD-ROM…)' box. Click 'Next >' to continue.



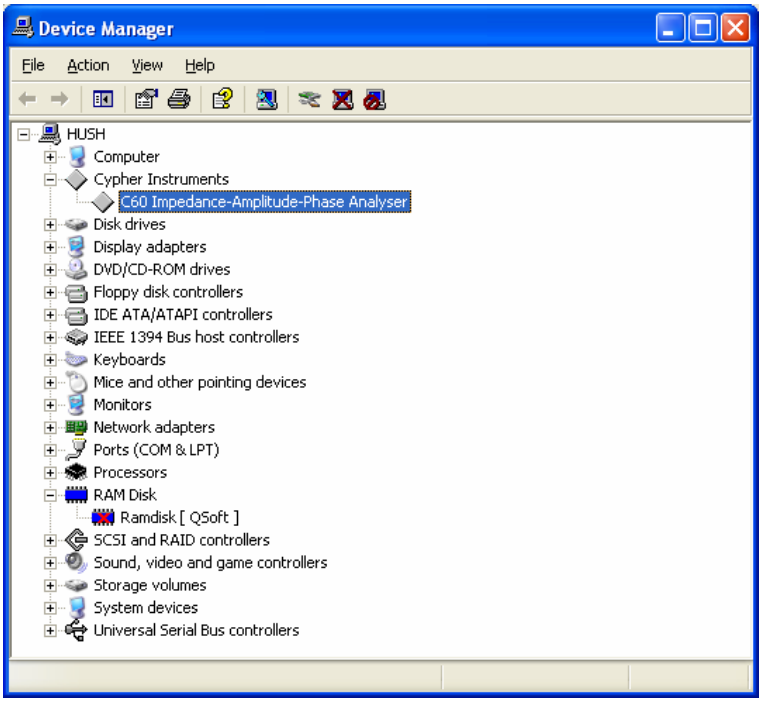
7. Windows will now copy the driver files from the CD-ROM to the hard disk.



8. Click 'Finish' to complete the driver installation.



9. The screen shot below shows the device driver has been properly installed.



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